United States Environmental Protection Agency | Region III Chesapeake Bay Program Office | Region III Water Protection Division | EPA 903-R-17-002 CBP/TRS 320-17 November 2017

In coordination with the Office of Water/Office of Science and Technology, Washington, D.C., and the states of Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia and the District of Columbia

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

2017 Technical Addendum

November 2017

Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2017 Technical Addendum

November 2017

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
Office of Science and Technology Washington, D.C.

and

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

Contents

Acknowledgements

This eighth addendum document since the April 2003 publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries* was developed and documented through a collaborative effort of the members of the Chesapeake Bay Program Science, Technical Assessment and Reporting Team's Umbrella Criteria Assessment Team, Criteria Assessment Protocol Workgroup, and Tidal Monitoring and Analysis Workgroup and the Water Quality Goal Implementation Team.

Principle and Contributing Authors

This document resulted from the collaborative expertise and talent of Chesapeake Bay Program partnership (the Partnership) state agency, federal agency, interstate river basin commissions, contract statistician and academic institutional partners. Unless noted, authors' affiliations are listed under the specific workgroup, team or committee acknowledgement. The principal authors (listed first) and contributing authors (listed in alphabetical order) follow by chapter:

Chapter 1. Peter Tango

Chapter 2. Peter Tango, Richard Batiuk U.S. Environmental Protection Agency Chesapeake Bay Program Office, Walter Boynton, Claire Buchanan, Matt Hall, Will Hunley, Elgin Perry, Tish Robertson, and Mark Trice.

Chapter 3. Howard Weinberg and Peter Tango

Chapter 4. Liza Hernandez, University of Maryland Center for Environmental Studies, and Peter Tango

Chapter 5. Howard Weinberg, Rebecca Golden, Maryland Department of Natural Resources, and Peter Tango

Chapter 6. Peter Tango

Criteria Assessment Protocol Workgroup

Peter Tango, Chair, United States Geological Survey/Chesapeake Bay Program Office; Melissa Merritt, Staff, Chesapeake Research Consortium/Chesapeake Bay Program Office; John Backus, Maryland Department of the Environment; Thomas Barron, Pennsylvania Department of Environmental Protection; Clifton Bell, Brown and Caldwell; Mark Bennett, United States Geological Survey; Lucretia Brown, District of Columbia Department of the Energy and the Environment; Claire Buchanan, Interstate Commission on the Potomac River Basin; Bill Dennison, University of Maryland Center for Environmental Science; Sherm Garrison, Maryland Department of Natural Resources; William Hunley, Hampton Roads Sanitation District; Arianna Johns, Virginia Department of Environmental Quality; Cindy Johnson, Virginia Department

of Environmental Quality; Renee Karrh, Maryland Division of Natural Resources; John Kennedy, Virginia Department of Environmental Quality; Rodney Kime, Pennsylvania Department of Environmental Protection; Michael Lane, Old Dominion University; Roberto Llanso, Versar Inc; Bruce Michael, Maryland Department of Natural Resources; Hassan Mirsajadi, Delaware Department of Natural Resources and Environmental Control; Ken Moore, Virginia Institute of Marine Science; Tom Parham, Maryland Department of Natural Resources; David Parrish, Virginia Institute of Marine Science; Elgin Perry, Statistical Consultant; Scott Phillips, United States Geological Survey; Tish Robertson, Virginia Department of Environmental Quality; John Schneider, Delaware Department of Natural Resources and Environmental Control; Donald Smith, Virginia Department of Environmental Quality; Cleo Stevens, Virginia Department of Environmental Quality; Matthew Stover, Maryland Department of the Environment; Richard Tian, University of Maryland Center for Environmental Science; Mark Trice, Maryland Department of Natural Resources; Howard Weinberg, University of Maryland Center for Environmental Science; David Wolanski, Delaware Department of Natural Resources and Environmental Control; John Wolf, United States Geological Survey; Joseph Wood, Chesapeake Bay Foundation; and Qian Zhang, University of Maryland Center for Environmental Sciences.

Umbrella Criteria Assessment Team

Peter Tango, Coordinator, United States Geological Survey/ Chesapeake Bay Program Office; Walter Boynton, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Claire Buchanan, Interstate Commission on the Potomac River Basin; Matt Hall, Maryland Department of Natural Resources; Jeni Keisman United States Geological Survey/Chesapeake Bay Program Office; Mike Lane, Old Dominion University; Elgin Perry, Statistical Consultant; and Tish Robertson, Virginia Department of Environmental Quality.

Water Quality Goal Implementation Team

James Davis Martin, Chair, Virginia Department of Environmental Quality; Teresa Koon, Vice Chair, West Virginia Department of Environmental Protection; Lucinda Power, Coordinator, U.S. Environmental Protection Agency; David Wood, Staff, Chesapeake Research Consortium/Chesapeake Bay Program Office; Lindsey Gordon, Staff, Chesapeake Research Consortium/Chesapeake Bay Program Office; Bill Angstadt, Delaware Maryland Agribusiness Association; Lee Currey, Maryland Department of the Environment; Dinorah Dalmasy, Maryland Department of the Environment; Sarah Diebel, United States Department of Defense; Jim George, Maryland Department of the Environment; Ann Jennings, Chesapeake Bay Commission; Veronica Kasi, Pennsylvania Department of Environmental Protection; Bill Keeling, Virginia Department of Environmental Quality; Sara Latessa, New York State Department of Environmental Conservation; Jackie Lendrum, New York State Department of Environmental Conservation; Beth McGee, Chesapeake Bay Foundation; Hassan Mirsajadi, Delaware Department of Natural Resources and Environmental Control; George Onyullo, District of Columbia Department of Energy and the Environment; Ted Tesler, Pennsylvania Department of Environmental Protection; Marel King, Chesapeake Bay Commission; John Schneider, Delaware

Department of Natural Resources and Environmental Control; Mary Searing, District of Columbia Department of Energy and the Environment; Jennifer Sincock U.S. Environmental Protection Agency; Tanya Spano, Metropolitan Washington Council of Governments; Chris Thompson, Lancaster County Conservation District; Suzanne Trevena, U.S. Environmental Protection Agency; Jenn Volk, University of Delaware; and Kristen Wolf, Pennsylvania Department of Environmental Protection.

Scientific and Technical Advisory Committee

The support and expert advice of all the members of the Chesapeake Bay Program's Scientific and Technical Advisory Committee, under the leadership of Dr. Lisa Wainger, University of Maryland Center for Environmental Sciences, and the Executive Secretarial support of Dr. Bill Ball, Natalie Gardner, and Rachel Dixon, Chesapeake Research Consortium, are hereby acknowledged. The Scientific and Technical Advisory Committee convened a panel of independent scientific experts to provide expert advice and direction on a set of criteria assessment issues and procedures. The members of the Panel were: Dr. Mary Christman, University of Florida; Dr. Marjy Friedrichs, Virginia Institute of Marine Science; Dr. Ken Moore, Virginia Institute of Marine Science; Dr. Malcolm Scully, Woods Hole, Oceanographic Institute; Dr. Jian Shen, Virginia Institute of Marine Science; and Dr. Steve Weisberg, Southern California Coastal Water Research Project. The contributions of the independent scientific peer reviewers—selected and convened by the Chesapeake Bay Program's Scientific and Technical Advisory Committee based on their recognized national expertise and drawn from institutions and agencies across the country—are hereby acknowledged.

Chesapeake Bay Program Partners

Without the efforts of the hundreds of colleagues involved in all aspects of field collection, laboratory analysis, management, and interpretation of Chesapeake Bay Monitoring Program data over the past three decades, these enhanced and new criteria assessment procedures could not have been developed.

The individual and collective contributions from members of U.S. EPA Region 3 Office and U.S. EPA Headquarters Office of Water are acknowledged: Mark Barath, Christopher Day, Erica Fleisig, Kelly Gable, Jim Keating, Evelyn MacKnight, and Bill Richardson. The individual and collective contributions from members of the Chesapeake Bay Program Office are also acknowledged: Howard Weinberg, University of Maryland Center for Environmental Science/Chesapeake Bay Program Office, and John Wolf, United States Geological Survey Chesapeake Bay Program Office.

Supporting analyses and syntheses were contributed by the following partners: Dr. Iris Anderson, Virginia Institute of Marine Science; Dr. Eva Bailey, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Dr. Donna Bilkovic, Virginia Institute of Marine Science; Dr. Walter Boynton, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Dr. Mark Brush, Virginia Institute of Marine Science; Dr. Claire Buchanan, Interstate

Commission on the Potomac River Basin; Dr. Amy Drohan, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory; Matt Hall, Maryland Department of Natural Resources; David Jasinski, Chesapeake Environmental Communications; Dr. Howard Kator, Virginia Institute of Marine Science; Mike Lane, Old Dominion University; Marcia Olson; Elgin Perry, Statistics Consultant; Dr. Tish Robertson, Virginia Department of Environmental Quality; David Rudders, Chesapeake Research Consortium; and Dr. Lisa Wainger, University of Maryland Center for Environmental Sciences Chesapeake Biological Laboratory.

chapter i

Introduction

In April 2003, the U.S. Environmental Protection Agency (EPA) published, on behalf of its seven jurisdictional partners, 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, on behalf of its seven jurisdictional partners, 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 Chesapeake 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). This 2017 addendum is the eight addendum document developed through the Partnership and published by EPA.

The detailed procedures for assessing attainment of the Chesapeake Bay water quality criteria continued to be advanced through the collective and collaborative 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, duration, return frequency, 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 full partner involvement, stakeholder input, and independent scientific review. Through the work of its Criteria Assessment Protocol Workgroup[1], the Chesapeake Bay Program (CBP) partnership has an established, long-standing forum for resolving issues, factoring in new scientific findings, and ensuring consistent bay-wide criteria assessment procedure development and management implementation. The Criteria Assessment Protocol Workgroup draws upon the talents and input from state, federal, river basin commission, and academic, as well as regional and local government and municipal authority partners. This sixth Chesapeake Bay water quality 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 (U.S. EPA 2004a, 2007a, 2007b, 2008, 2010).

Chapter 2 documents recommendations for assessment of short duration Chesapeake Bay dissolved oxygen criteria based on a conditional attainment approach or a combination of sub-segmenting open-water designated use segments in up to three possible zones and applying the different criteria assessment procedures protective of each zone and the applicable criterion.

Chapter 3 documents the water column volumes in three Chesapeake Bay segments—Western Branch Patuxent River Tidal Fresh, Maryland portion of Anacostia Tidal Fresh, and Patuxent River Tidal Fresh—where the water column volumes had not been estimated and, therefore, were limiting reporting in Maryland's Clean Water Act 303(d) listing assessments.

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

Chapter 5 documents an update to the Chesapeake Bay underwater bay grasses restoration goal and alignment of the goal with the four jurisdictions' Chesapeake Bay water quality standards' underwater bay grasses restoration acres.

Chapter 6 documents refinements to how the Chesapeake Bay benthic index of biotic integrity assessment of the aquatic life use should be applied in undertaking water quality 303(d) listing status supporting aquatic life use assessments.

[1] http://www.chesapeakebay.net/groups/group/criteria_assessment_protocol_workgroup

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

This document represents the sixth 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 Chesapeake Bay water quality 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.

LITERATURE CITED

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

U.S. EPA (U.S. Environmental Protection Agency). 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003*. EPA 903-R03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

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

U.S. EPA (U.S. Environmental Protection Agency). 2005. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. 2005 Addendum. December 2005*. EPA 903-R-05-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

U.S. EPA (U.S. Environmental Protection Agency). 2007b. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries –Chlorophyll a Addendum. October 2007*. EPA 903-R-07-005. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. EPA (U.S. Environmental Protection Agency). 2008. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2008 Technical Support for Criteria Assessment Protocols Addendum. September 2008.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

chapter ii

Assessing Short-Duration Dissolved Oxygen Criteria Attainment

BACKGROUND

U.S. EPA has published and Delaware, Maryland, Virginia, and the District of Columbia (referred to here as the Chesapeake Bay jurisdictions) have adopted into their respective state's water quality standards regulations, the dissolved oxygen criteria protective of the published migratory spawning and nursery, open-water, deep-water and deep-channel designated uses (Table II-1) (U.S. EPA 2010a). These dissolved oxygen 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 dissolved oxygen criterion with a temporal period of less than the 30-day mean used to support assessments of the four Chesapeake Bay jurisdictions' Chesapeake Bay water quality standards.

Enhanced monitoring remains a viable option for filling dissolved oxygen criteria assessment gaps. Alternatively, estimating probable attainment of a dissolved oxygen 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 on the states' Chesapeake Bay water quality standards attainment. 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 by habitat and providing methods and decision-making rules offers further options to provide sufficient monitoring to assess all applicable temporal scales of the Chesapeake Bay dissolved oxygen criteria. This chapter provides documentation for recommended monitoring and assessment procedures to ensure the four Chesapeake Bay jurisdictions can fully assess all their short-duration Chesapeake Bay dissolved oxygen criteria for protection of all designated uses adopted into their state's water quality standards regulations.

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

1. When water column temperatures are greater than 29 °C, an open water dissolved oxygen criterion for the instantaneous minimum of 4.3 mg/L is applied to protect habitat for survival of shortnose sturgeon.

Source: U.S. EPA 2003a

SEGMENT LEVEL ASSESSMENT

The Chesapeake Bay Program partners have used various forms of a basic segmentation scheme to organize collection, analysis and presentation of environmental data for more than three decades. The *Chesapeake Bay Program Segmentation Scheme Revisions, Decisions and Rationales: 1983-2003* (U.S. EPA 2004b) provides documentation on the development and evolution of the spatial segmentation scheme of the Chesapeake Bay and its tidal tributaries. For the purpose of water quality attainment assessment, the four tidal water Chesapeake Bay Program partner jurisdictions have coordinated with U.S. EPA to create subsegement assessment units. The following guidance first describes criteria attainment assessment options at the full segment scale, then support for options to address the segment scale assessment through sub-segment assessments.

DIRECT ASSESSMENT WITH ENHANCED MONITORING

The four Chesapeake Bay jurisdictions always have the option of collecting water column profiles of dissolved oxygen concentration at high enough frequencies to support direct assessments of each dissolved oxygen criterion's temporal period—7-day mean, 1-day mean, and 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 profilers, 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, 2004a, 2007, 2008, 2010a) (see Table II-6).

ASSESSING CONDITIONAL ATTAINMENT ACROSS DISSOLVED OXYGEN CRITERIA

Conditional attainment refers to using the mathematical relationship between results of computing one statistic from a set of dissolved oxygen concentration measurements collected to support water quality standards attainment assessments at a specific temporal scale (e.g., 30-day mean) to evaluate dissolved oxygen 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 directly supports 30-day mean dissolved oxygen assessments, however, the monitoring program has thus far been considered insufficient on its own to assess short-duration dissolved oxygen criteria (U.S. EPA 2003a, CBP STAC 2012).

For example, the open-water designated use has a set of summer season dissolved oxygen criteria that includes a 30-day mean, 7-day mean and instantaneous minimum that must be met simultaneously for a Chesapeake 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 dissolved oxygen standards assessment for the 30-day mean portion of the three applicable criteria (see Table II-1).

The concept of conditional attainment as an assessment approach uses the idea of an umbrella-like dissolved oxygen criterion effect to support multiple criteria assessments 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 dissolved oxygen threshold from one scale of measurement is meant to provide levels of habitat protection for one or more other, shorter duration, dissolved oxygen habitat protection criteria.

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.

Demonstrating Conditional Dissolved Oxygen Attainment

Through the recent efforts of the Chesapeake Bay Program Scientific, Technical Assessment and Reporting Team's Criteria Assessment Protocol Workgroup, the Chesapeake Bay Program partnership explored the relationship between 30-day mean dissolved oxygen measurements and 7-day mean, 1-day mean and instantaneous minimum measurements in the same 30-day period. The Partnership's analysts used Chesapeake Bay-specific, geographically diverse, high temporal density water quality data sets that covered tidal fresh to polyhaline salinities and mainstem Chesapeake Bay as well as tidal tributary and embayment habitats (Appendix A, B, C). 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 dissolved oxygen criteria, the scientific and management communities have developed a foundation of understanding regarding habitat protections between measured criteria (e.g., 30-day mean) averaging periods and unassessed, shorter duration temporal scales of dissolved oxygen criteria attainment (e.g., 7-day mean, 1 day mean and instantaneous minimum).

Historical Evidence Demonstrating Conditional Attainment

Previously, Jordan et al. (1992) developed regression equations to derive the seasonal mean concentrations that could be presumed protective of target, shorter-duration assessment dissolved oxygen thresholds in a given Chesapeake Bay segment. They concluded that knowing the seasonal mean dissolved oxygen concentration for a given region in the Bay permitted "a good estimate of what proportion of actual dissolved oxygen observations are likely to meet, or fail to meet, each of the target dissolved oxygen concentrations". Further, in 2004, CBP analysts explored mutual protection among the new 2003 Chesapeake Bay dissolved oxygen criteria with different durations (U.S. EPA 2003a). Olson et al. (cited in U.S. EPA 2004a) primarily used 147 buoy-based, high temporal frequency dissolved oxygen data sets collected between1987-1995 (where dates were noted) from the EPA's Environmental Monitoring and Assessment Program. The data sets are geographically diverse in their collections, represent tidal fresh to polyhaline habitats, and have measurements from the mainstem Chesapeake Bay as well as tidal tributaries and embayments (Table V-2 in U.S. EPA 2004a). They documented that: 1) the open-water 30-day mean dissolved oxygen criterion attainment was generally protective of the open-water 7-day mean dissolved oxygen criterion and instantaneous minimum in those segments where both criteria applied; and 2) the deep-water 30-day mean dissolved oxygen criterion attainment was generally protective of the 1-day mean and instantaneous minimum dissolved oxygen criteria.

Similarly, mutual protection between one measured dissolved oxygen criterion and a second dissolved oxygen criterion of a different duration was tested in the course of developing the 2010 Chesapeake Bay Total Maximum Daily Loads (TMDL). Analysts at the Chesapeake Bay Program Office conducted an assessment of how well dissolved oxygen criteria that are already measured with the current Chesapeake Bay Program partnership's long term water quality monitoring program mutually protected the attainment of unmeasured, short-duration dissolved oxygen criteria (U.S. EPA 2010b, 2010c).

Using hourly output from a calibration run of the Partnership's Chesapeake Bay Water Quality Sediment Transport Model, the Chesapeake Bay Program Office analysts produced a summer season test of the "umbrella criterion". Note that for the purposes of developing the 2010 Chesapeake Bay TMDL, the summer season (June 1 – September 30) was assumed to be the limiting season in all designated uses being assessed for dissolved oxygen impairments (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 dissolved oxygen 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 tidal water segments in Chesapeake Bay), non-attainment rates of the summer instantaneous minimum dissolved oxygen 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 three dissolved oxygen 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". That is, these criteria are 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 additional support for using an approach of estimating conditional attainment to address water quality standards attainment decisions for unmeasured criteria. However, further evidence of the suitability of the approach was requested by Chesapeake Bay Program partners before adopting this criteria attainment procedure into the Bay jurisdictions' water quality standards regulations.

Recent Evidence Demonstrating Conditional Attainment

Perry (cited in CBP STAC 2012) conducted a study on conditional dissolved oxygen water quality standards attainment across different scales of dissolved oxygen criteria when measuring one scale, the 30-day mean. Perry notes that in order for the summer open-water 30-day mean dissolved oxygen criterion to serve as a conditional criteria attainment measure for the 7-day mean dissolved oxygen criterion, there was the need to show that if the 30-day mean dissolved oxygen criterion was satisfied, there was a small probability that the 7-day mean dissolved oxygen criterion was going to be violated. Using 'less than 10 percent' as an acceptable risk of wrongly concluding that the 7-day mean dissolved oxygen 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 dissolved oxygen criterion of 4.0 mg/L while the monthly mean is at the 30-day mean dissolved oxygen criterion of 5.0 mg/L would be about 10 percent (Figure II-1). This scenario would be strong evidence that the 30-day mean criterion is mutually protective of habitat with the 7-day mean dissolved oxygen criterion of 4.0 mg/L.

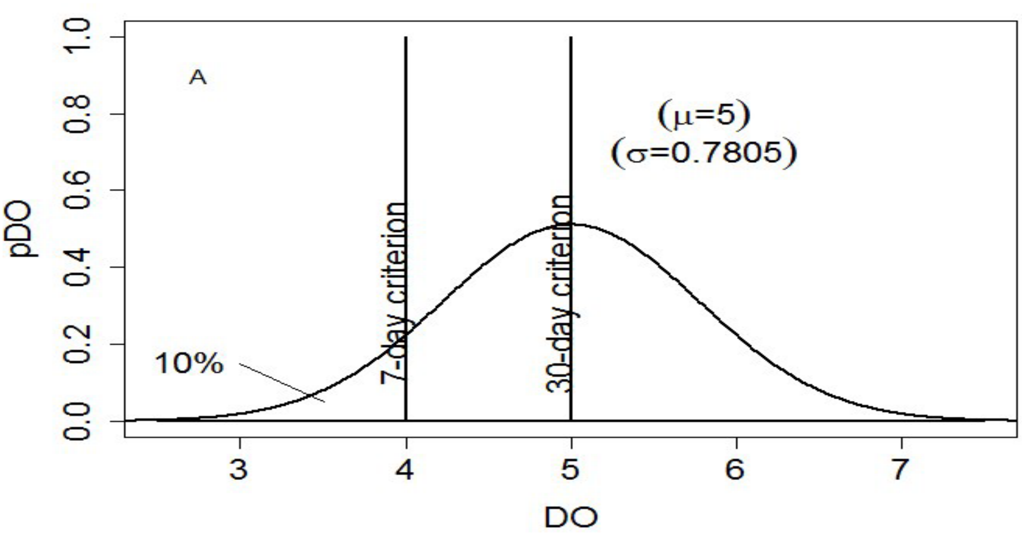

Figure II-1. Illustration of the 30-day mean criterion serving to simultaneously protect the 7-day mean criterion when the standard deviation of the differences between the monthly mean and weekly mean is 0.7805 or less.

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 was 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-2, blue dashed line). However, increasing the monthly mean dissolved oxygen concentration to 5.285 mg/L again brings the risk of violations of the 7-day mean dissolved oxygen criterion to an acceptable level of 10 percent (Figure II-2, blue solid line). Perry also completed a complementary study of conditional attainment using depth specific data from offshore continuous monitoring sites in the Chesapeake Bay that had a range of dissolved oxygen means (Appendix A). The violations rates were computed and produced comparable results to Perry's previously cited analysis (i.e., CBP STAC 2012).

Because it is unlikely that under the natural conditions of the Chesapeake Bay and its tidal tributaries and embayments, the monthly mean will hover in this narrow window of dissolved oxygen concentrations (5.0 to 5.285 mg/L) for an extended time then it seems reasonable to consider that the 7-day criterion is satisfied if the 30-day mean dissolved oxygen criterion is satisfied. This evidence is one key supporting fact for the CBP Scientific, Technical Assessment and Reporting Team's Umbrella Criteria Assessment Team conclusion that the 30-day mean dissolved oxygen criterion is mutually protective for the 7-day mean dissolved oxygen 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 dissolved oxygen concentrations (i.e., data collected at 15 minute intervals through the Chesapeake Bay Program's Shallow-water Water Quality Monitoring Program).

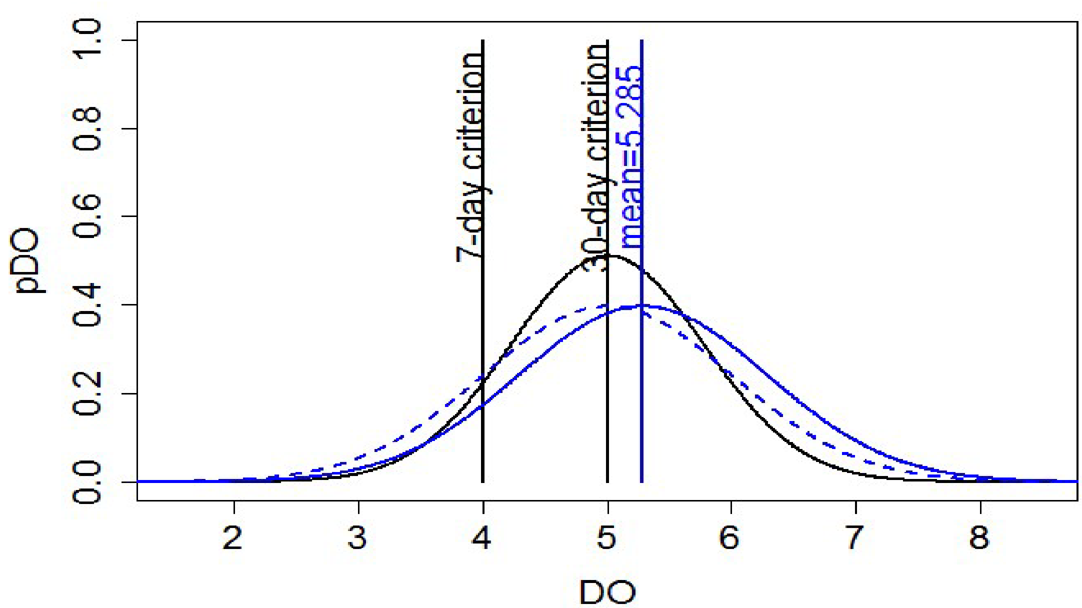

Figure II-2. Illustration of the change in the distributions from an ideal (black line) to account for natural dissolved oxygen dynamics in the Bay (dashed blue line) and subsequent shift in the monthly mean required to meet 10% risk tolerance for the 7-day mean criterion when the weekly mean deviation is 1.005 (solid blue line).

By contrast, the Chesapeake Bay Program long term fixed station water quality monitoring program collects dissolved oxygen profiles through the water column one to two times a month which serves as the basis for assessing attainment of the 30-day mean dissolved oxygen water quality standard. When the 30-day mean dissolved oxygen concentration is estimated by a sample size of two observations then the variability of the deviations between the 30-day mean dissolved oxygen estimate and the 7-day dissolved oxygen means increases by 60 to 90 percent (Figure II-3). 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-3, 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-3, red solid line).

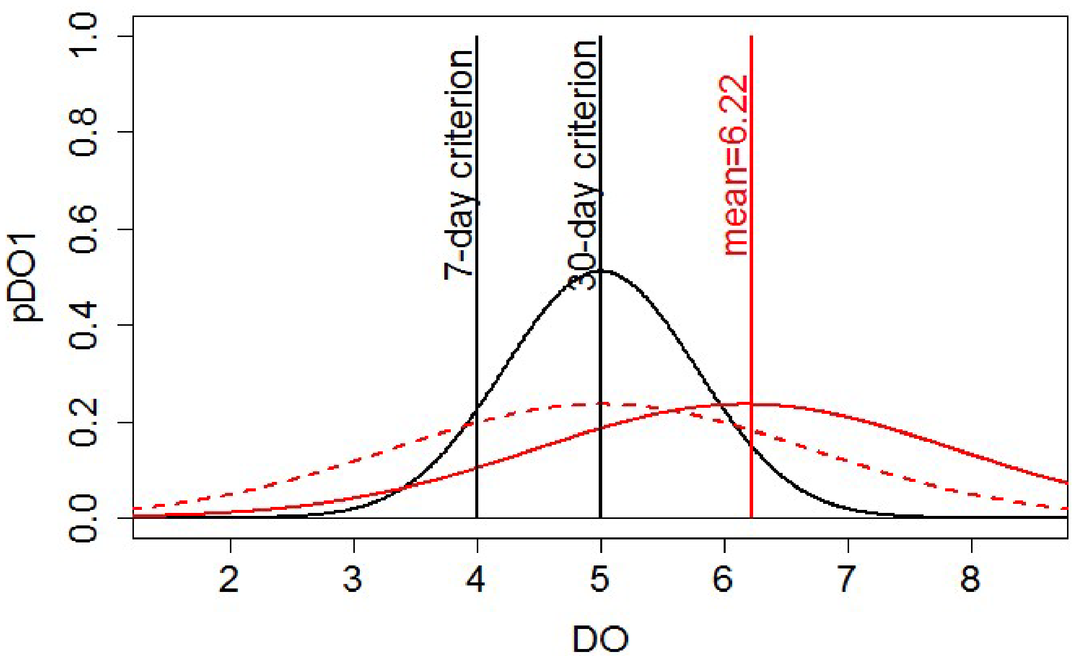

Figure II-3. Illustration of the shift—from red dashed line to red solid line—in the monthly mean required to meet 10% risk tolerance for the 7-day criterion when the weekly mean deviation of 1.74 accounting for the uncertainty in estimating the mean due to small sample sizes (n=2).

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 dissolved oxygen dynamics to generate time series that have properties similar to observed Chesapeake Bay dissolved oxygen 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 Olson (cited in U.S. EPA 2004a). Details of the autoregressive modeling approach are provided in Appendix A.

Results of the autoregressive analysis demonstrate protection levels for meeting a 30-day mean dissolved oxygen concentration and mutually protecting the summer open-water instantaneous minimum criterion are presented in Table II-2. Whereas we previously saw achievable thresholds in protection of the 7-day mean dissolved oxygen 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 high as 7.01 mg/L. 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 to the instantaneous minimum criterion (e.g., approximately 25% if meeting a 30-day mean threshold of 6.3 based on Table II-2).

The selection of an appropriate level of acceptable risk is a decision to be made by individual jurisdictions with consultation with EPA. If the selection of an appropriate level of acceptable risk yields a dissolved oxygen concentration which can't be routinely achieved, then direct measurement or other assessment methods are recommended for evaluating attainment of the instantaneous minimum dissolved oxygen criteria.

Table II-2. Parametric simulation results for a gradient of dissolved oxygen mean data and their ability to mutually protect the summer, open-water instantaneous minimum dissolved oxygen criteria.

Summer Season, Open-water 30-day Mean Dissolved Oxygen (mg/L)				
Rate of instantaneous criterion > 10 percent	5.0058	5.6732	6.3407	7.0082
	47.6%	32.5%	25.3%	18.5%

Source: CBP STAC 2012

Example of Conditional Attainment Assessment

An example of the relevance of this range of 30-day mean dissolved oxygen concentrations documented in Table II-2 was developed. Table II-3 below illustrates the application of the conditional attainment assessment for the 2011-2013 Chesapeake Bay open-water summer season designated use dissolved oxygen 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. This is based on the standard CFD attainment assessment (U.S. EPA 2003a, 2010a).

Next, for the sake of illustration, we want to apply the conditional attainment approach and show segments that simultaneously meet the 30-day mean dissolved oxygen criterion and the 7-day mean dissolved oxygen mean criterion without having the temporal density of measurements to support direct water quality standards attainment assessment of the 7-day mean dissolved oxygen criterion. 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 dissolved oxygen concentration threshold to achieve simultaneous protection is 6.1 mg/L.[2]

Table II-3. Conditional attainment assessment approach applied using two threshold values to show mutual protection for the 30-day and 7-day mean open-water dissolved oxygen criteria.

Segments attaining the 30-day mean dissolved oxygen criterion.	Segments that further pass attainment of the 7-day mean dissolved oxygen criterion using a 6.1 mg/L 30-day mean dissolved oxygen threshold[1].	Segments that also pass the 7-day mean dissolved oxygen criterion using a 6.5 mg/L 30-day mean dissolved oxygen threshold.
CB1TF, CB3MH, CB4MH, CB5MH, CB8PH, CHSMH, EASMH, JMSMH, JMSPH, JMSTFU, MPNTF, PIAMH, PMKTF, POCMH, MPCMH, VPCMH, POTMH, POTMH_MD, POTOH_VA, POTTF, POTTF_DC, POTTF_MD, TAMMH, APPTF, BIGMH, BOHOH, C&DOH, CHKOH, ELKOH, FSBMH, MANMH, CB5MH_MD, MIDOH, NANMH, NORTF, PISTF, SASOH, SEVMH, SOUMH, CB5MH_VA	POCMH, POCMH_MD, POCMH_VA, POCOH_VA, APPTF, BIGMH, FSBMH, MANMH	None

1.The subset of segments that further pass attainment of the 30-day mean dissolved oxygen criterion using 6.1 mg/L dissolved oxygen threshold for assessing mutual protection of the 7-day mean dissolved oxygen criterion (less 10 percent risk of nonattainment) based on 2 samples each month, June-September 2011-2013.

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 threshold in place of the 5.0 mg/L threshold for assessing simultaneous protection of the 7-day dissolved oxygen mean based on the 30-day dissolved oxygen mean. The assessment of passing or failing are now interpreted as evidence for meeting the 7-day dissolved oxygen mean and the 30-day dissolved oxygen mean while accounting for uncertainty due to the CBP water quality monitoring program’s 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 dissolved oxygen threshold of 6.1 mg/L, providing protection of the open-water designated use under the 7-day dissolved oxygen mean criterion considering the uncertainty of measuring the 30-day dissolved oxygen mean from two days each month (Table II-3). These 8

2. 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-3 has a similar standard deviation of 1.74. See Appendix A for the associated reference table.

segments, which met the 6.1 mg/L threshold supported by a 10 percent level of acceptable risk decision-rule, can be effectively stated as also in attainment for the 7-day mean dissolved oxygen 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 mean criteria 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 dissolved oxygen mean criterion: CB1TF, CB3MH, CB5MH, PIAMH, POTTF_DC, GUNOH, CB5MH_MD, NORTF, SASOH, SOUMH, and CB5MH_VA (Table II-3). 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 criterion for dissolved oxygen.

Protecting other short duration criteria may require using more stringent dissolved oxygen 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, 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 (Table II-3). Three Eastern Shore Maryland segments are, however, less than 1 percent from meeting the 6.5 mg/L threshold (NORTF, FSBMH, and BIGMH). This finding provides an important perspective when considering the instantaneous minimum dissolved oxygen criteria that needs a 30-day mean dissolved oxygen assessment well above 7.01 mg/L in order to be in attainment.

Therefore, conditional attainment assessment provides a viable method of assessment. However, the robustness of the technique to discriminate mutual criteria attainment or impairment for measured and unmeasured criteria at different time scales is sensitive to the uncertainty in sampling effort underlying the estimate of a 30-day mean. Under the existing sampling effort of the Partnership's long term Chesapeake Bay water quality monitoring program, this uncertainty generates decision thresholds that appear to be unattainable measures of dissolved oxygen concentrations (Table II-2). Yet, 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 alternative acceptable risk levels of non-attainment need to be considered to address assessment of the instantaneous minimum criterion.

Application of Conditional Criteria Attainment Assessment

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

Temporal sampling density must be accounted for in order to use conditional dissolved oxygen 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 dissolved oxygen concentration of 5.3 mg/L can simultaneously protect open-water habitat by ensuring the 7-day mean dissolved oxygen concentrations will remain above 4 mg/L 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 dissolved oxygen 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 dissolved oxygen concentrations coincident with evaluating the means with a low sample density, a 30-day mean dissolved oxygen must now be at least 6.1 mg/L 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 dissolved oxygen attainment assessment methodology.

For a 30-day mean dissolved oxygen 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 dissolved oxygen mean criterion, the 30-day mean dissolved oxygen must be equal to or greater than 5.3 mg/L, 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 dissolved oxygen must now achieve a threshold of at least 6.22 mg/L in order to allow for a less than 10 percent non-attainment to protect the habitat with the 7-day mean dissolved oxygen criterion (Figure II-3). However, for deep-water designated use habitat which has different criteria thresholds than the open-water designated use habitat, Olson et al. (cited in U.S. EPA 2004a) determined a direct assessment of the 30-day mean attainment effectively evaluates protection for the 1-day mean and instantaneous minimum dissolved oxygen criteria.

The risk of non-attainment for a short duration criterion relative to a 30-day mean dissolved oxygen 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 dissolved oxygen 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 and a low level of acceptable risk of nonattainment is selected. There are two options available to account for this finding: 1) sample more frequently to better account for dissolved oxygen variability; or 2) define a different level of acceptable risk of nonattainment.

This criteria assessment approach is based on the existing Chesapeake Bay Program partnership's long-term Chesapeake Bay and Tidal Tributaries 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, 2004a, 2007, 2008, 2010a). The conditional criterion attainment approach can be used by jurisdictions to assess their open-water 7-day mean dissolved oxygen criterion. In deep-water designated use segments, assessment of the 30-day mean dissolved oxygen criterion directly serves to protect the 1-day mean and the instantaneous minimum dissolved oxygen criteria (see Recommended Methods for Assessing Short Duration Dissolved Oxygen Criteria Attainment, this chapter). Additional monitoring and research can be used to develop segment- and designated use-specific relationships to be applied in a conditional attainment assessment approach to assessing Chesapeake Bay dissolved oxygen water quality standards.

FRAMING THE ASSESSMENT OF OPEN-WATER SHORT DURATION DISSOLVED OXYGEN CRITERIA

Assessing the full array of open-water short duration dissolved oxygen criteria builds on the recognition that even within an individual 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 in shallow water habitats vs. relatively constant dissolved oxygen concentrations over extended periods of times in open, more well-mixed habitats. 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 may be assessed using different assessment procedures while at the same time still ensuring full protection of the open-water designated use.

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 more than three decades. The *Chesapeake Bay Program Segmentation Scheme Revisions, Decisions and Rationales: 1983-2003* (U.S. EPA 2004b) provides documentation on the development and evolution 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 and 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 then monitor the response.

As documented in detail in Appendix B, 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 created for state-specific Chesapeake Bay water quality standards applications (U.S. EPA 2004c, 2007a). The U.S. EPA (2003b) 305(b) guidance similarly highlights the Washington State Department of Ecology's 3-zone approach to water quality assessment in estuarine habitats. In this EPA national guidance, 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 (2003b) 305(b) 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 further supported by Caffrey (2004) and Boynton 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) also 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 tidal tributaries had greater violation rates than monitoring sites exposed to the open waters of the mainstem Chesapeake Bay (Boynton et al. 2014).

Acknowledging that there is a scientific basis showing habitat differences exist in open-water habitats (Appendix A) (Boynton et al. 2014), and EPA and state policies and procedures are 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 2007, VADEQ 2014), a jurisdiction may specifically delineate sub-segments within an individual Chesapeake Bay segment's open-water designated use for purposes of dissolved oxygen criteria attainment assessment.

Three Zones within the Open-Water Designated Use

The existing published Chesapeake Bay designated uses call for two zones—open, well-mixed waters and shallow-water waters (U.S. EPA 2003a, 2003c). Boynton et al. 2014 provide a solid rationale for adding a third zone—tributaries of tributaries.

Applying the concept of three zones to Chesapeake Bay open-water habitats yields the following physically delineated three zones illustrated in Figure II-4 and described below along with the underlying rationale for each zone.

<u>Zone 1</u>

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

Rationale: These well-mixed tidal waterbodies are represented by the 92 Chesapeake Bay segments delineated and refined over the past 30+ years of the Chesapeake Bay Program partnership (U.S. EPA 2004b, 2005a).

<u>Zone 2</u>

Shallow-water waters: waters generally equal to or less than 2 meters in depth[1].

Rationale: Shallow-waters are well recognized and documented as a distinct designated use habitat supporting underwater bay grasses and having unique water quality conditions compared with other tidal habitats (Dennison et al. 1993, Kemp et al. 2004, U.S. EPA 2003a, 2003c).

<u>Zone 3</u>

Tributaries of tributaries off of the mainstem Chesapeake Bay and its tidal tributaries and embayments: waters with weak hydrodynamic links to open waters of the mainstem bay and mainstem of tidal tributaries. These waters are considered poorly mixed.

Rationale: Boynton et al. (2014) provided in-depth analyses which provided for clear delineation of tidal water bodies which were well removed and isolated from more open, well-mixed tidal waters and, therefore, displayed different water quality conditions.

The actual scale and specific delineations of these three zones will be determined on a case-by-case basis through consultation between the individual Chesapeake Bay jurisdictions and EPA, consistent with past published Chesapeake Bay criteria guidance (U.S. EPA 2007a).

---

1. On May 15, 2014, the CBP Scientific and Technical Assessment and Reporting Team's Criteria Assessment Protocol Work Group reached a consensus decision that, while the shallow-water bay grass designated use may have a 2 meter contour boundary, for the purpose of dissolved oxygen attainment assessments, there is not a single depth contour that would be applied baywide at this time to define shallow water. Final decisions on sub-segment boundaries would be determined on a segment-specific basis, as necessary, based on consultations between each of the four the Chesapeake Bay jurisdictions and EPA.

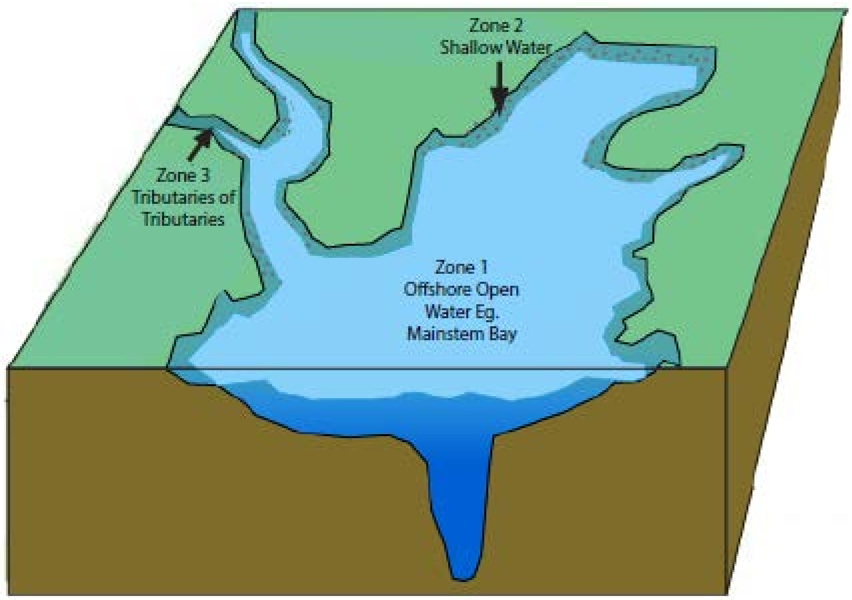

Figure II-4. Applying the concept of three zones to Chesapeake Bay open-water habitats.

CRITERIA ASSESSMENT PROCEDURES TAILORED TOWARDS THE THREE ZONES

Given the option for creating the delineation of the three zones based on their unique dissolved oxygen dynamics and mixing characteristics, distinct sets of criteria assessment procedures can be aligned with each zone (Table II-4). 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. By meeting the instantaneous minimum dissolved oxygen criterion in the sub-segment zones 2 and 3, the defacto decision is that the entire open-water designated use segment meets the instantaneous minimum criterion and is, therefore, in attainment with this criterion.

Table II-4. Applicable criteria assessment procedures for each of the three zones within the open-water designated use.

Zone	Zone Description	Applicable Criteria Assessment Procedures
1	Open, well-mixed mainstem Bay and tidal tributary waters	• 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 • Continuous monitoring-based assessment of the instantaneous minimum
2	Shallow-water waters	• Continuous monitoring-based assessment of the instantaneous minimum
3	Tributaries of tributaries off of the mainstem Chesapeake Bay and its tidal tributaries	• Discrete sampling-based assessment of the instantaneous minimum

Continuous Monitoring-Based Assessment

Continuous monitoring data sensors are in use evaluating shallow-water habitat conditions throughout the summer season in Chesapeake Bay (U.S. EPA 2010b). Continuous monitoring data are not currently used in dissolved oxygen criteria attainment assessments as standard practice (U.S. EPA 2010a). The technological and statistical challenge of mixing nearshore high frequency data with low frequency offshore data over multiple depths for an open-water dissolved oxygen criteria attainment assessment has been overcome. However, the results remain subject to the uncertainty imposed by the lowest common denominator in the monitoring data, the estimate of a monthly mean at the long term water quality monitoring stations using no more than 2 samples per month. The opportunity to sub-segment out and separately assess attainment in the nearshore habitats where the continuous monitoring sensors are routinely monitoring presents the ability to now assess attainment of the open-water instantaneous minimum dissolved oxygen criterion directly with high frequency dissolved oxygen data.

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

- Virginia – "10%-10% rule": a water body is impaired if exceedances were observed more than 10% of the time within more than 10% of the 24-hour periods monitored (VADEQ 2016).

- Wisconsin – "10% rule": a water body is impaired if exceedances were more than 10% of the time (WDNR 2015).

- Louisiana – "25% rule": a water body is impaired if violations were observed more than 25% of the time (LDEQ 2016).

- Washington – "3 daily minimum values rule": a water body is impaired if at least 3 daily minimum values are below the instantaneous minimum (WDE 2012).

- New Jersey – "2 daily minimum values rule": a water body is impaired if at least 2 daily minimum values are below the instantaneous minimum (NJDEP 2015).

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

Based on the above published state methods and EPA guidance, the CBP Scientific, Technical Assessment and Reporting Team's Criteria Assessment Protocol Workgroup worked with U.S. EPA Region III Office staff to develop options for assessing attainment of season-long, high frequency data (e.g., every 15 minutes) for criterion assessment that protects the designated use. The Criteria Assessment Protocol Workgroup then considered three options for instantaneous minimum criterion assessment that account for concerns of living resource protection over an entire season at a conservative level.

<u>Rule 1</u>. No more than 10 percent of days during a single season with an exceedance— 9 total of 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.

<u>Rule 2</u>. 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.

<u>Rule 2-Alternate</u>. 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 (Table II-5). Therefore, based on the assumption that the instantaneous minimum criterion is interpreted as a discrete 1 hour average condition (i.e., for Chesapeake Bay jurisdictions, the computations start at midnight and there are 24 discrete hourly calculations for each day. This approach is contrasted with the option that may be applied elsewhere (e.g. recommendations for assessment in Delaware, tidal Murderkill River, Hydroqual 2014) of using a rolling 1-hour average that would be calculated every 15 minutes to produce 96 hourly results for the instantaneous minimum criterion assessment each day) 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 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.

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 (see Table II-6) using data from at least 2 stations in the zone.

Table II-5. Testing of the three potential rules for assessing instantaneous minimum criterion assessment using continuous monitoring dissolved oxygen data.

Segment	Year	Rule 1	Rule 2	Rule 2 (Alt)*
JMSMH	2006	Pass	Fail	Pass
	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
	2012-2013	Fail	Fail	Fail

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

Discrete Monitoring-based Assessment

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-4) (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 over 3 years. At least 50 percent of the samples must be collected before 9 AM to address diel variability in dissolved oxygen concentrations. Dissolved oxygen criteria attainment is based on 10 percent allowable exceedance of the applicable instantaneous minimum criterion.

For those waterbodies for which sub-segmenting them for their own criteria assessment makes sense due to their isolated nature (see Zone 3 in Table II-4), taking a discrete sampling approach which relies on additional sampling beyond that accomplished by the existing Chesapeake Bay Program Partnership's long term water quality monitoring program is the best choice. The specifications of the discrete sampling need to be robust enough to provide confidence in the attainment assessment of that sub-segment yet not resource intensive enough to prevent its routine application.

RECOMMENDED METHODS FOR ASSESSING SHORT-DURATION DISSOLVED OXYGEN CRITERIA ATTAINMENT

The methods described above and summarized in Table II-6, when adopted directly or by reference into the four Chesapeake Bay jurisdictions' water quality standards regulations, should be used to assess short duration dissolved oxygen criteria across all designated uses. In combination with the criteria assessment methods previously approved by the Partnership and published by EPA (U.S. EPA 2003a, 2004a, 2007, 2008, 2010a), these combined sets of dissolved oxygen criteria assessment methods provide the four Chesapeake Bay jurisdictions with the ability to make water quality standards attainment and impaired waters listing and delisting decisions for all 92 Chesapeake Bay segments and for all five designated uses based on assessments of all applicable criteria protecting those designated uses.

Table II-6. Recommended methods for assessing attainment of the short duration Chesapeake Bay dissolved oxygen criteria.

Designated Use	Assessment Scale		Assessment Method	Criteria	Supporting Documentation
All Designated Uses	Segment		**Direct Assessment with Enhanced Monitoring** Collecting data beyond the existing fixed station monitoring network using vertical water quality profilers, autonomous underwater vehicles, citizen science, etc.	All	U.S. EPA 2003a, U.S. EPA 2004a, this document
			Conditional Attainment with Monitoring Data Meet the longest duration mean dissolved oxygen threshold associated with a defined level of acceptable risk of nonattainment of the short duration dissolved oxygen criterion/criteria		
Open-water Designated Use	Full segment assessed with shoreline to shoreline Application	Segment	**Conditional Attainment with Bimonthly Monitoring Data** Meet the 30-day mean dissolved oxygen threshold associated with a defined level of acceptable risk of nonattainment of the 7-day mean dissolved oxygen criterion	7-day mean	U.S. EPA 2003a, U.S. EPA 2004a, CBP STAC 2012, this document
			Meet the 30-day mean dissolved oxygen threshold associated with a defined level of acceptable risk of nonattainment for the instantaneous minimum criterion	Instantaneous minimum	
	Sub-segment approach application	Zone 1: Open, well-mixed waters	**Zone 2 and Zone 3 Attainment Decision Rule** If sub-segments Zone 2 and Zone 3 pass, then the Zone 1 sub-segment is deemed passing and the entire segment is considered in attainment for the instantaneous minimum criterion	Instantaneous minimum	This document
			Conditional Attainment Meet the 30-day mean dissolved oxygen threshold associated with a a defined level of acceptable risk of nonattainment of the 7-day mean dissolved oxygen criterion	7-day mean, Instantaneous minimum	U.S. EPA 2003a, U.S. EPA 2004a, CBP STAC 2012, this document
		Zone 2: Shallow-water waters	**Continuous Monitoring** 15 minute interval data collected over the entire summer season with no more than two consecutive days with 10% time exceedance	Instantaneous minimum	This document
		Zone 3: Isolated Waters	**Discrete Sampling** 10 sample events per year collected over 3 years assessed based on 10% allowable exceedance	Instantaneous minimum	This document
Deep-water Designated Use	Segment		**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 2004a

LITERATURE CITED

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

Caffrey, J.M. 2004. Factors controlling net metabolism in U.S. estuaries. *Estuaries* 27(1):90-101.

CBP STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee). 2012. *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*: Findings of the Umbrella Criterion Action Team, Tidal Monitoring and Analysis Workgroup. August 2012, STAC Publication. 12-02.

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

Dunk, J.R., W.J. Zielinski and H.H. Welsh. 2006. *Evaluating reserves for species richness and representation in northern California*. Diversity and Distributions 12, 434-442.

Hydroqual. 2014. Tidal Murderkill River site-specific dissolved oxygen criteria. Report to the Delaware Department of Natural Resources and Environmental Control. 73pp.

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

Kemp, W.M., R.A. Batiuk, R. Bartleson, P. Bergstrom, V. Carter, C.L. Gallegos, W. Hunley, L. Karrh, E. Koch, J.M. Landwehr, K.A. Moore, L. Murray, M. Naylor, N.B. Rybicki, J.C. Stevenson, and D.J. Wilcox. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality, light regime and physical-chemical factors. *Estuaries* 27(3):363–377.

Launer, A. and D. Murphy. 1994. Umbrella species and the conservation of habitat fragments: a case of a threatened butterfly and a vanishing grassland ecosystem. *Biological Conservation*, 69 (2): 145-153.

LDEQ (Louisiana Department of Environmental Quality). 2015. *Louisiana's 2016 Integrated Report and Section 303(d) List Methods and Rationale.* Baton Rouge, LA. February 2016.

NJDEP (New Jersey Department of Environmental Protection). 2015. Draft 2016 *New Jersey Integrated Water Quality Assessment Methods*. Trenton, NJ. December 2015.

Roberge, J. and P. Angelstam. 2004. Usefulness of the umbrella species concept as a conservation tool. *Conservation Biology*, 18 (1): 76-85

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

U.S. EPA (U.S. Environmental Protection Agency). 2003b. *Guidance for 2004 Listing and Reporting Requirements Pursuant to Sections 303(d) and 305(b) of the Clean Water Act, July 21, 2003.* U.S. Environmental Protection Agency Office of Water, Office of Wetlands, Oceans and Watersheds, Assessment and Watershed Protection Division, Watershed Branch, Washington D.C.

U.S. EPA (U.S. Environmental Protection Agency). 2003c. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* EPA 903-R03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

U.S. EPA (U.S. Environmental Protection Agency). 2004b. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003.* EPA 903-R-04-008. CBP/TRS 268/04. U.S. Environmental Protection Agency, Region III, Chesapeake Bay Program Office, Annapolis, MD.

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

U.S. EPA (U.S. Environmental Protection Agency). 2005a. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. 2005 Addendum. December 2005*. Region III Chesapeake Bay Program Office, Annapolis, MD. EPA 903-R-05-004.

U.S. EPA (U.S. Environmental Protection Agency). 2005b. *Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act*. U.S. Environmental Protection Agency, Office of Water, Office of Watershed, Oceans, and Wetlands, Assessment and Watershed Protection Division, Washington, DC.

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

U.S. EPA (U.S. Environmental Protection Agency). 2008. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2008 Technical Support for Criteria Assessment Protocols Addendum. September 2008.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

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

U.S. Environmental Protection Agency. 2010c. *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.

VADEQ (Virginia Department of Environmental Quality). 2014. *Water Quality Assessment Guidance Manual for 2014 305(b)/303(d) Integrated Water Quality Report*. April 2014, Richmond, VA.

VADEQ (Virginia Department of Environmental Quality). 2016. Water Quality Assessment Manual for 2016 303(d)/305(b) Integrated Water Quality Report. Guidance Memo No. 16-2005. June 2016. Richmond, VA.

WDE (Washington Department of Ecology). 2012. *Water Quality Program Policy: Assessment of Water Quality for the Clean Water Act Section 303(d) and 305(b) Integrated Report.* July 2012. Olympia, WA.

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

WDNR (Wisconsin Department of Natural Resources). 2015. *Wisconsin 2016 Consolidated Assessment and Listing Methodology (WisCALM) for CWA Section 303(d) and 305(b) Integrated Reporting.* Guidance #3200-2015-01. March 2015. Madison, WI.

chapter iii

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

BACKGROUND

Criteria attainment assessments for the applicable designated use-based dissolved oxygen criteria are assessed on the basis of how much of the total volume of the segment's designated use habitat achieved the criterion values over what time period (U.S. EPA 2003, 2008, 2010a). Quantifying the water column volume of each of the 92 Chesapeake Bay segments is required for conducting water quality criteria attainment assessments using the Partnership's Chesapeake Bay interpolator. However, three segments have not previously been assigned water volumes despite the fact that long-term water quality monitoring stations are present and active within each segment. These three segments are the Western Branch Patuxent River Tidal Fresh (WBRTF), the Anacostia Tidal Fresh Maryland (ANATF MD), and the Patuxent River Tidal Fresh (PAXTF). The location of these segments is illustrated in Figure III-1. In this chapter, water volumes are assigned and the basis for decisions on the volume assignments are provided in Appendix D.

For more than 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 (U.S. EPA 2004). 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 and embayments. Subsequently, a U.S.

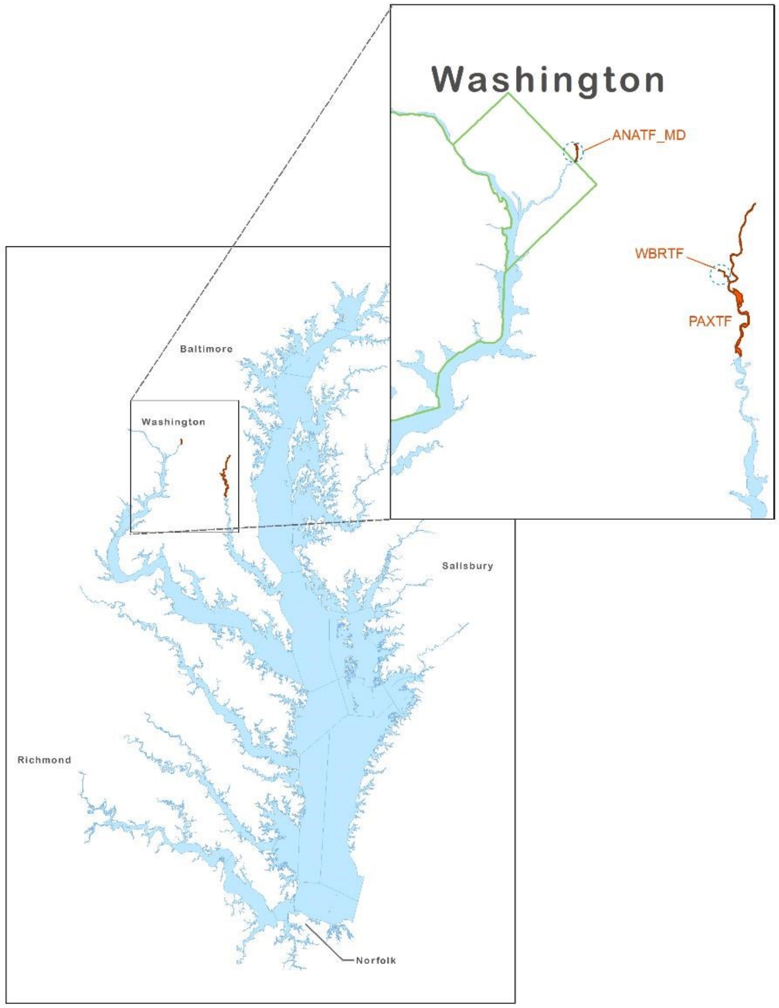

Figure II-1. The location of three segments that previously lacked volume estimates needed to assess their Chesapeake Bay water quality standards attainment: Western Branch Patuxent tidal Fresh (WBRTF), Patuxent River tidal fresh (PAXTF) and Anacostia River tidal fresh in Maryland (ANATF_MD).

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 2010 Chesapeake Bay Total Maximum Daily Load (TMDL) (U.S. EPA 2010b).

WBRTF SEGMENT VOLUME

The Western Branch Patuxent River Tidal Fresh (WBRTF) 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). In the past, no volume estimate was available for WBRTF (see Table 1 in U.S. EPA 2004) due to an absence of bathymetry data. However, recently 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 establish a volume for WBRTF of 111,567 cubic meters (m^3) (Appendix D). Water volumes and the data used to determine the volume assignment are provided in Appendix D and E.

ANATF MD AND PAXTF SEGMENT VOLUMES

Insufficient bathymetry data have prevented development of volume estimates for the Anacostia River Tidal Fresh Maryland (ANATF MD) and Patuxent River Tidal Fresh (PAXTF) segments. As interim volume estimates to allow for calculations of water quality standards attainment assessments using the Chesapeake Bay Interpolator, the CBP Criteria Assessments Protocol Workgroup worked with MDE to reach agreement on using interim segment volumes as they are expressed in the Partnership's Chesapeake Bay Water Quality Sediment Transport Model (U.S. EPA 2010b) (Appendix D) used to support the 2017 mid-point assessment of the Chesapeake Bay TMDL:

- PAXTF segment model-based volume is 11,025,000 m^3; and
- ANATF MD model-based volume estimate is 172,500 m^3.

These interim volume estimates will continue to be used until the time at which more detailed field measurements of the bathymetry of both segments becomes available.

LITERATURE CITED

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

U.S. EPA (U.S. Environmental Protection Agency). 2004. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. October 2004*. Region III Chesapeake Bay Program Office, Annapolis, MD. EPA 903-R-04-008.

U.S. EPA (U.S. Environmental Protection Agency). 2005. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. 2005 Addendum. December 2005*. Region III Chesapeake Bay Program Office, Annapolis, MD. EPA 903-R-05004.

U.S. EPA (U.S. Environmental Protection Agency). 2008. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2008 Technical Support for Criteria Assessment Protocols Addendum.* EPA 903R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

U.S. 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 **iv**

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

BACKGROUND

For decades, the Chesapeake Bay Program partnership has separately tracked and reported on dissolved oxygen, water clarity/underwater bay grasses and chlorophyll *a* indicators to chronicle changes in Chesapeake Bay ecosystem 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 2010 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 Chesapeake Bay 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 into their respective water quality standards. This chapter documents this water quality standards based multi-metric Chesapeake Bay water quality indicator used for tracking progress in response to nutrient and sediment load reduction actions taken across the Chesapeake Bay watershed and airshed.

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 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)* (U.S. EPA. 2003a) and subsequent supporting documentation (U.S. EPA 2003b, 2004a, 2004b, 2005, 2007a, 2007b, 2008, 2010a). The documentation presents EPA's recommended regionally-based nutrient and sediment enrichment criteria expressed as dissolved oxygen, water clarity/underwater grasses and chlorophyll *a* criteria applicable to the Chesapeake Bay, its tidal tributaries and embayments.

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. The original 2003 *Regional Criteria Guidance* and subsequently published supporting documentation has provided Delaware, Maryland, Virginia and the District of Columbia with recommendations for establishing water quality standards consistent with Section 303(c) of the Clean Water Act. These four jurisdictions have subsequently adopted into their water quality standards regulations a set of scientifically defensible water quality criteria that are protective of designated and existing uses for Chesapeake Bay and its tidal tributaries (U.S. EPA 2010b). The four tidal water jurisdictional partners and EPA continue to work collaboratively to assess water quality standards attainment based on the criteria applicable to the five Chesapeake Bay designated uses (Figure IV-1).

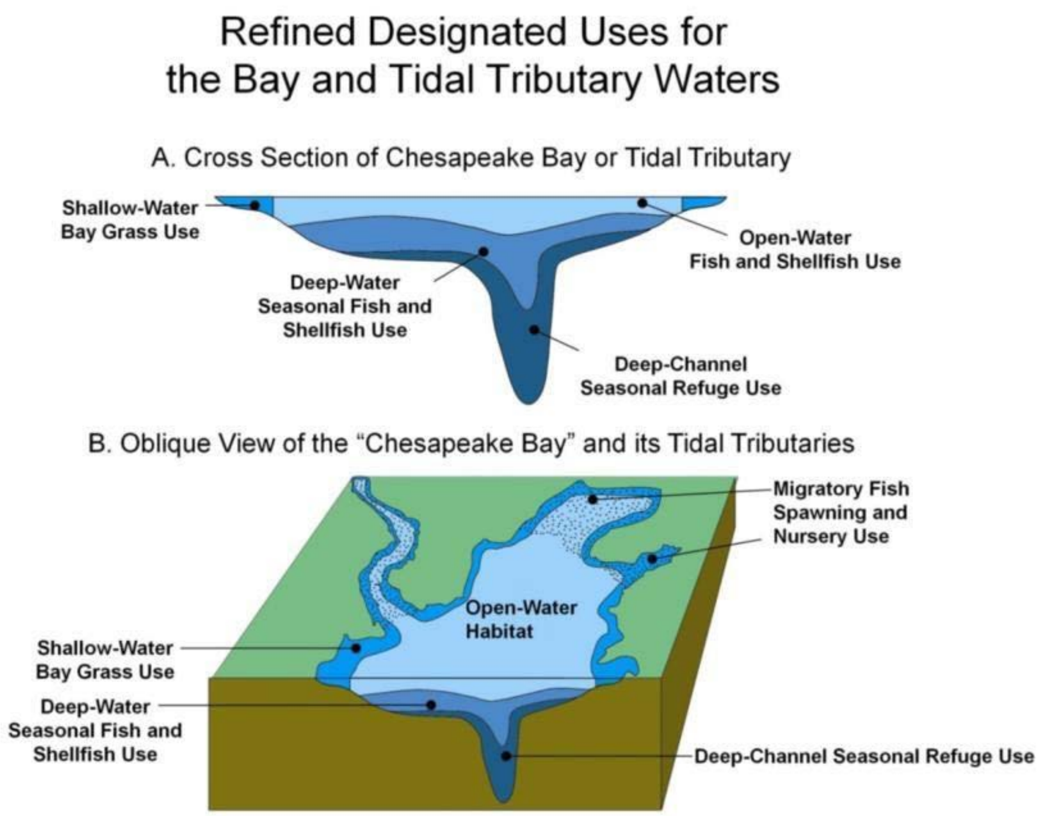

Figure IV-1. Conceptual illustration of the five Chesapeake Bay tidal water designated use zones. Source: U.S. EPA 2003b

The Presidential Chesapeake Bay Executive Order 13508 and supporting strategy published in 2010 supported 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*".

This chapter provides a brief overview of the attainment assessment method, the hierarchy of attainment measures providing context on bay-wide attainment, segment attainment, designated use attainment and criterion attainment, and the structure and calculation of the multi-metric indicator including the rules that support indicator computation.

CRITERIA ATTAINMENT ASSESSMENT METHODOLOGIES

Attainment for dissolved oxygen and chlorophyll *a* criteria is computed by using water quality monitoring data collected from the Chesapeake Bay Program partnership Chesapeake Bay Mainstem and Tidal Tributary Water Quality Monitoring Programs' fixed station network or through DATAFLOW data collections in the Partnership's Shallow-Water Water Quality Monitoring Program during a 3-year assessment period and applying the cumulative frequency distribution (CFD) criteria attainment assessment methodology (Table IV-1) (U.S.EPA 2003a, 2004a, 2007a, 2007b, 2008, 2010a). Attainment for water clarity/underwater bay grasses criteria is calculated as the single best year of underwater bay grass acres coverage in the 3-year assessment period to compare with segment specific goal acreages or as water clarity goal acres, or as the published measures that combine the two measures to compare against the water clarity goal acres (U.S. EPA 2003a, 2004a, 2007a, 2008, 2010a).

Table IV-1. Chesapeake Bay dissolved oxygen, water clarity/underwater bay grasses and chlorophyll *a* criteria assessment methodologies.

Dissolved Oxygen The published dissolved oxygen criteria assessment methodology used for assessing Chesapeake Bay water quality standards attainment involves the comparison of two cumulative frequency distribution (CFD) curves—one based on a healthy habitat and one based on monitoring data collecting during the 3-year assessment period—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 *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*.
Water Clarity Attainment of the water clarity/underwater bay grasses criteria may be computed through one of three methods: measured underwater grass bed acres compared with the segment's restoration goal acreage; water clarity acres; or a combination of the two measures. The methodologies are described in Appendix E of *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*.
Chlorophyll *a* 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 chlorophyll *a* criteria attainment involves the comparison of two CFD curves—one based on a healthy habitat and one based on monitoring data collecting during the 3-year assessment period—in a two dimensional space of percent time and percent space to determine compliance with standards.

Sources: U.S. EPA 2007b, 2008.

FOUR LEVELS OF WATER QUALITY ATTAINMENT ASSESSMENT

Chesapeake Bay water quality criteria attainment is assessed at four levels (Figure IV-2):

1. *Criterion level*: each individual criterion applicable to the protection of a specific designated use;
2. *Designated-use level*: the combined set of criteria applicable to the protection of a specific designated use;
3. *Chesapeake Bay segment level*: the combined set of applicable designated uses within an individual Chesapeake Bay segments; and

4. *Chesapeake Bay-wide level*: the combined set of all 92 Chesapeake Bay segments that cover all the tidal waters of the Chesapeake Bay mainstem, its tidal tributaries, and embayments.

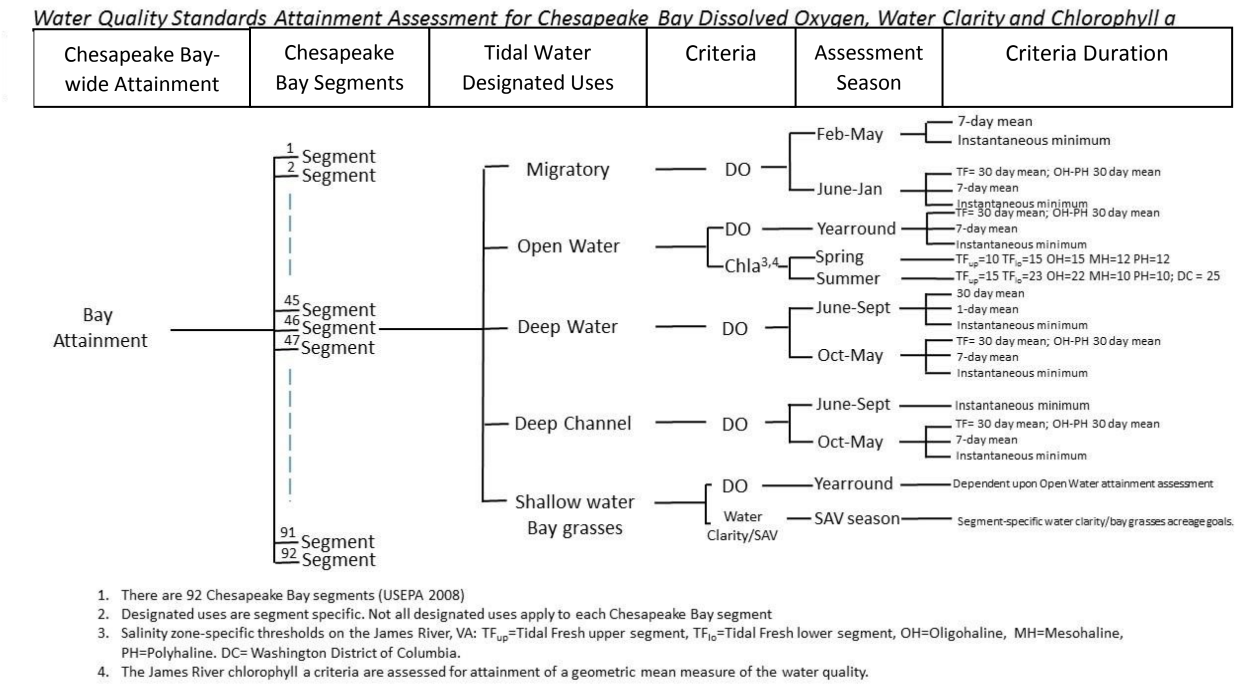

Figure IV-2. The relationships between Chesapeake Bay segments, designated uses, applicable water quality criteria, assessment seasons and criteria durations.

Criterion Assessment Level

At the criterion level of assessment, each dissolved oxygen, water clarity/underwater bay grasses or chlorophyll *a* criterion is assessed for attainment for protection of a specific designated use within an individual segment (Figure IV-2). Dissolved oxygen criteria apply at the summer (June-September), the rest of the year (October-May), or the migratory spawning and nursery (February 15-May 31) seasons. Chlorophyll *a* criteria apply in the tidal James River mainstem's open-water designated uses during separate spring (March-May) and summer (July-September) seasons. In the District of Columbia's tidal waters, the District's chlorophyll *a* criterion applies to all open-water segments only during the summer season (July-September).

Designated Use Assessment Level

At the designated use assessment level, all criteria applicable to a specific designated use must be determined to be in attainment in order for a segment's designated use to be considered in attainment. Each segment can have as few as one and as many as five applicable designated uses. Within each applicable designated uses for a segment, all the applicable criteria for protection of that use must attain all their respective dissolved oxygen, water clarity/underwater bay grasses or chlorophyll *a* criteria. A criterion may have a season-specific threshold in its application and some criteria may only apply to specific salinity zones. All those season-specific and salinity zone-specific criteria must also be achieved.

Chesapeake Bay Segment Assessment Level

At the Chesapeake Bay segment assessment level, for an individual Chesapeake Bay segment to be in attainment, all criteria for all applicable designated uses must be attained.

Chesapeake Bay-wide Assessment Level

Producing a Chesapeake Bay-wide water quality standards attainment assessment is based on combining all the criteria attainment results from all 92 Chesapeake Bay segments and all their applicable designated uses (Figure IV-3). There are 289 segment*designated use combinations (see Table 3-3 in U.S. EPA 2010b).

STRUCTURE OF THE MULTI-METRIC WATER QUALITY STANDARDS INDICATOR

The Multi-metric Water Quality Standards Indicator (Indicator) reports on the proportion of segment*designated use*criterion class combinations that meet all applicable season-specific thresholds for each 3-year assessment period (Figure IV-3, Table IV-2). Criterion class represents the water quality standard parameters as either dissolved oxygen, water clarity/underwater bay grasses or chlorophyll *a*. Further, each of the 92 Chesapeake Bay segments has been assigned its own unique surface area (see Table F-1 in Appendix F). Recognize that in addition, each designated use within each segment has been assigned its own unique surface area. The segments and their designated uses also have unique volumes. However, because there are wide disparities in size and volume of designated uses and segments, the Indicator avoided using a simple proportion of the number of criterion class*designated use-segments achieving attainment and dividing it by 289 criterion class*designated use*segment combinations for its tracking metric. While dissolved oxygen is evaluated for its volume-based attainment, water clarity/underwater bay grasses and chlorophyll *a* water quality standards attainment are assessed on a surface area basis. Since dissolved oxygen attainment could be expressed based on a surface area as well, segment surface area, as opposed to volume, was chosen as the common weighting factor. Recognizing the open-water designated uses' surface area is considered constant when measured at mean low water, but deep-water and deep-channel designated use surface areas vary in size depending on the water column conditions observed during each monitoring cruise, the open water surface area of each respective segment was therefore applied as a constant multiplier for all criterion class*designated use combinations in the indicator calculation.

Table IV-2. For the 289 Designated Use*criterion class*Segment combinations (contained within the 92 Chesapeake Bay segments), the Segment areas are summed[1].

Chesapeake Bay Tidal Water Designated Use*Criterion class.	Total Surface Area of Designated-Use Segments (km^2)
Migratory Fish Spawning and Nursery*Dissolved oxygen	5565101169.36
Open Water*Dissolved oxygen	11660174083.95
Open Water*CHLA = Open*CHLA(spring$_{\text{Virginia James River only}}$) + Open water*CHLA (summer$_{\text{Virginia James River + Washington DC waters}}$)	620327627.29
Deep Water*Dissolved oxygen	6932558324.18
Deep Channel*	4404190644.45
Shallow-Water Bay Grasses/Water Clarity	11558645485.84
Total area of the Segment*Designated Use*Criterion Class combinations used in the indicator calculations	**40740997335.07**

1. The sum of the areas by designated use*criterion class is equal to the total area constant used in the Indicator calculations.

The surface area of each segment multiplied by the number of applicable designated uses in each segment provides a common denominator for the indicator assessment. The indicator is, therefore, the sum of the products for the number of designated uses in attainment with all applicable criteria multiplied by their respective segment surface area across all 92 segments divided by the sum of the products for each segment-surface-area*number of designated uses applicable in the segment across all 92 segments. The resulting measure is multiplied by 100 to provide a percentage.

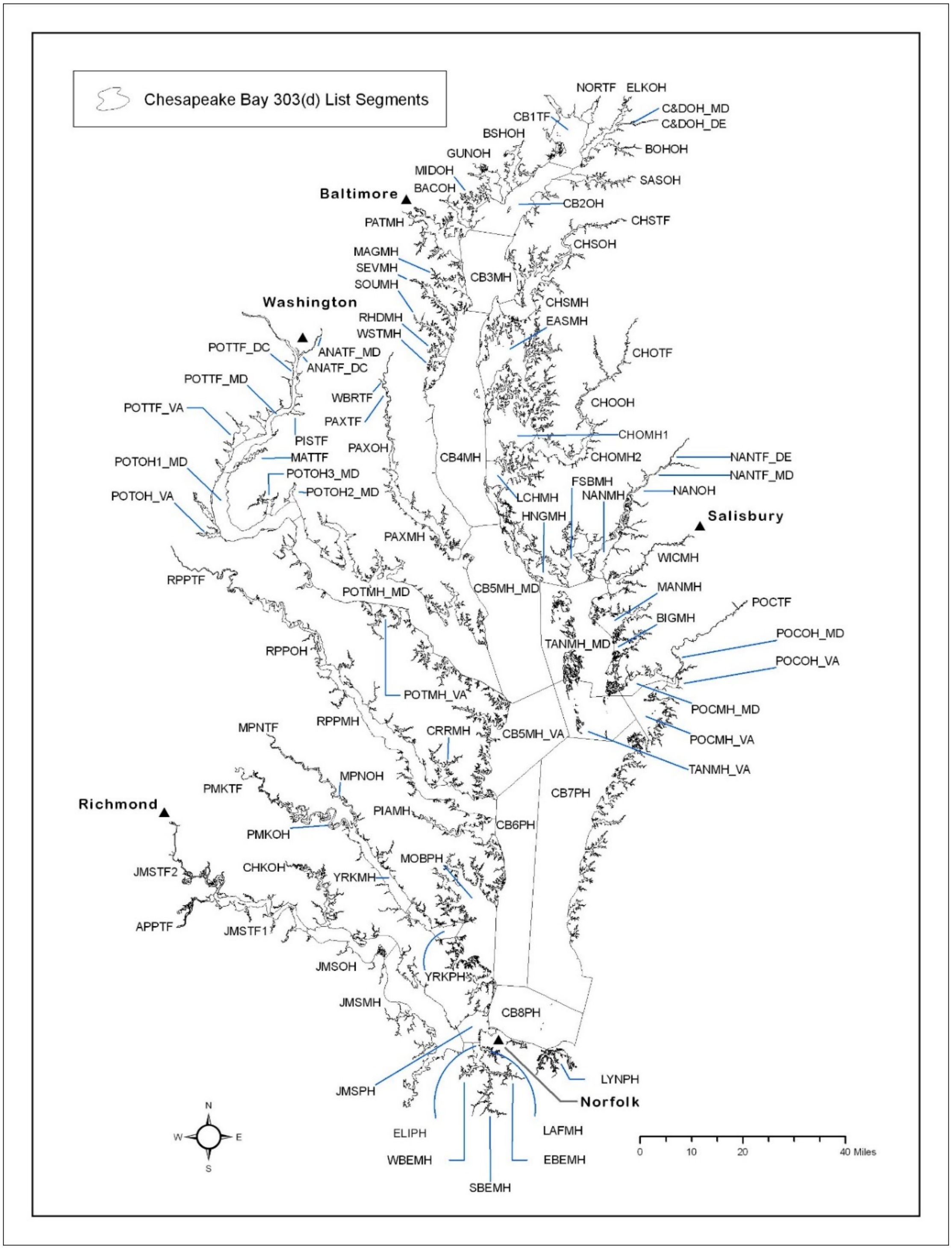

Figure IV-3. A map of the 92 Chesapeake Bay segments assessed in the Multi-metric Water Quality Standards Indicator analysis.
Source: USEPA 2008a

$MWQS\ Indicator =$

Step 1) Using the Chesapeake Bay Program Partnerships' water quality monitoring results for a three year water quality standards assessment period for each segment, if the criterion class condition is met for the applicable designated use in an assessment period (i.e., the assessment result passes for water quality standards attainment), add the surface area - expressed in kilometers^2 (km^2) - to create a sum of designated use*criterion class area of attainment

- see Appendix F for segments and their applicable designated use*criterion classes. There are 289 segment*(designated use*criterion class) combinations for evaluation.
- see **Rules for Computing the Indicator** in this chapter for the Indicator assessment process and results that equal attainment for each designated use*criterion class

Step 2) Divide the sum of segment*designated use*criterion class from step 1 by the sum of all available segment*designated use criterion class area (see Table IV-2. This sum is a constant that equals 40740997335.07 km^2)

Step 3) Multiply the quotient by 100 to express the result as a percent of water quality standards goal attained

RULES FOR COMPUTING THE INDICATOR

The Indicator was derived as an indexed accounting mechanism that estimates the sum of dissolved oxygen, water clarity/underwater bay grasses and chlorophyll *a* water quality standards attainment in Chesapeake Bay and its tidal tributaries. Outputs of the Indicator are used for tracking and publically reporting progress towards delisting all impaired segments of Chesapeake Bay and its tidal tributaries. The full set of rules for computing the Indicator is documented below. These rules apply strictly to computing the Indicator, not to assessing criteria attainment for making listing and delisting decisions.

Rule 1. Critical season is summer. Based on the best available science, the first rule was directed at having a critical season. The summer season was considered the limiting season for the 2010 Chesapeake Bay TMDL with respect to achieving water quality standards (U.S. EPA 2010b). Therefore, the first rule was directed at dissolved oxygen criteria attainment such that if a segment met its summer season criteria, it was considered to meet all its applicable criteria for the year and, therefore, attain all the criteria protective of all applicable dissolved oxygen designated uses strictly for the purposes of computing this indicator (Figure IV-4).

Rule 2. Meet the applicable 30-day mean dissolved oxygen criteria and all short duration criteria are also considered attained. Until Delaware, the District of Columbia, Maryland and Virginia's existing Chesapeake Bay water quality standards regulations are revised to reflect the assessment procedures for the full array of applicable dissolved oxygen criteria described in Chapter 2 of this document, strictly for the computing and presentation of this indicator, it is assumed that attainment of the 30-day mean summer open-water and deep-water dissolved oxygen criterion can serve as an "umbrella" assessment protective of the remaining short duration dissolved oxygen criteria in each applicable designated use.

Rule 3. Applicable criteria-based concentrations and durations which apply for computing the Indicator.

- Migratory Fish and Spawning Nursery Designated Use: 6 mg/L 7-day mean dissolved oxygen criterion applied as a 30-day mean for February-May
- Open-Water Fish and Shellfish Designated Use: 5 mg/L 30-day mean dissolved oxygen criteria
- Deep-Water Seasonal Fish and Shellfish Designated Use: 3 mg/L 30-day mean dissolved oxygen criteria
- Deep-Channel Seasonal Refuge Designated Use: 1 mg/L instantaneous minimum dissolved oxygen criteria
- Shallow-Water Bay Grasses Designated Use: Refer to the underwater bay grasses restoration goal acreages by segment to evaluate standards attainment (See Chapter V, Table V-1 this document). However, when water clarity assessment data is available the shallow-water bay grasses designated use is considered in attainment if:
    1. Sufficient acres of underwater bay 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 bay grass acreage for that segment; or
    3. Assessment of 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:
    1. Tidal mainstem James River segments: criteria attainment assessed during the spring (March 1-May 31) and summer (June 1-September 30) seasons; **both seasons must meet the applicable criteria for the segment to be in attainment**
    2. District of Columbia's tidal Potomac River and Anacostia River segments: criteria attainment only assessed during the summer (June 1-September 30) season

LITERATURE CITED

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

U.S. EPA (U.S. Environmental Protection Agency). 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability. October 2003.* EPA 903-R03-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

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

U.S. EPA (U.S. Environmental Protection Agency). 2005. *Chesapeake Bay Program Analytical Segmentation Scheme: Revisions, Decisions and Rationales 1983-2003. 2005 Addendum. December 2005*. EPA 903-R-05-004. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

U.S. EPA (U.S. Environmental Protection Agency). 2007b. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries –Chlorophyll a Addendum. October 2007*. EPA 903-R-07-005. Region III Chesapeake Bay Program Office, Annapolis, MD.

U.S. EPA (U.S. Environmental Protection Agency). 2008. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2008 Technical Support for Criteria Assessment Protocols Addendum. September 2008.* EPA 903-R-08-001. Region III Chesapeake Bay Program Office, Annapolis, MD.

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

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

chapter V

Aligning the Chesapeake Bay Program's Underwater Bay Grasses Restoration Goal with the Jurisdictions' Chesapeake Bay Water Quality Standards

BACKGROUND

Chesapeake Bay Program Office staff identified the difference between the underwater bay grasses restoration goal target (185,000 acres) adopted by the Chesapeake Bay Program partnership in 2003 and the subsequent underwater bay grasses 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 underwater bay grasses acres due to estimated acres of underwater bay grasses that were 'clipped' from underwater bay grasses beds when applying the GIS analyses. 'Clipped' areas represented the difference between the GIS-based shoreline delineation and actual shorelines in the aerial photographs. 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 Delaware, Maryland, Virginia, and the District of Columbia's Chesapeake Bay water quality standards. This chapter documents the updating the Chesapeake Bay Program partnership's underwater bay grasses restoration goal.

The underwater bay grasses acreage goals were developed as part of a larger effort to restore Chesapeake Bay water quality. In 1993, the Chesapeake Executive Council formally adopted its first underwater bay grasses 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 and the adoption of those criteria along with Chesapeake Bay designated uses into state water quality standards regulations by the tidal bay jurisdictions of Delaware, Maryland, Virginia and the District of Columbia (Chesapeake Executive Council 2000, U.S. EPA 2003a, U.S. EPA 2010).

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 Midpoint 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* and the October 2003 *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability* (U.S. EPA 2003a, 2003b). The four Chesapeake Bay jurisdictions subsequent promulgation of their respective 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 (U.S. EPA 2010).

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 grasses restoration goal totals. The two workgroups jointly reviewed the details of how the original 185,000 acre underwater bay grasses restoration goal derived which then served as the foundation for the four Chesapeake Bay jurisdictions promulgating the underwater bay grasses restoration acres into their Chesapeake Bay water quality standards. In revising the underwater bay grasses restoration goal, the jurisdictions had the benefit of the body of history used to develop the 185,000 acre goal, new information available after EPA's publication of the 2003 Chesapeake Bay criteria and designated uses documents (U.S. EPA 2003a, 2003b), and the jurisdictions' adoption of the Bay water quality criteria and tidal water designated uses into their Chesapeake Bay water quality standards regulations (U.S. EPA 2010). In adopting segment-specific water clarity/underwater bay grasses restoration acreage-based water quality standards, the four Chesapeake Bay jurisdictions more accurately reflected segment-based underwater bay grasses goal acreages (U.S. EPA 2003b). 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 of and track changes towards attaining the shallow-water bay grasses designated use's water clarity and underwater bay grasses restoration acreages criteria.

This chapter reviews the history of establishing Chesapeake Bay underwater bay grasses restoration acreage goals supporting the assessment of water quality standards attainment for the water clarity criteria for protection of the shallow-water bay grass designated use. The results of this review supported updating the Chesapeake Bay Program partnership's underwater bay grasses restoration goal to be consistent with the four tidal Bay jurisdictions combined Chesapeake Bay water quality standards-based underwater bay grasses restoration acreages, presently totaling 192,000 acres.

HISTORY OF DEVELOPING THE UNDERWATER BAY GRASSES RESTORATION GOAL

The original tiered targets supporting an underwater bay grasses restoration acreage goal for Chesapeake Bay were first published in the 1992 underwater bay grasses 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 grasses 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 underwater 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 grasses 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 grasses aerial survey digital data sets, including a thorough quality assurance evaluation, which resulted in corrections to the original data (Batiuk et al. 2000). 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 grasses 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 grasses 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 baywide underwater grasses restoration goal[3]. 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 (640,926 acres) minus underwater acres from declared underwater bay grasses no-grow zones (U.S. EPA 2003b, p. 119).

RESTORATION GOAL AND WATER QUALITY STANDARDS UNDERWATER BAY GRASSES RESTORATION ACREAGES COMPARISON

During 2013 and early 2014, the CBP Habitat Goal Implementation Team's Submerged Aquatic Vegetation Workgroup reviewed the goal setting methodology used to derive the 2003 Chesapeake Bay underwater bay grasses restoration acreage goal. Chesapeake Bay Program Office staff, working with the SAV Workgroup, identified differences between the segment-specific underwater bay grasses 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 grasses restoration goal setting effort preceded the 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 bay grasses 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 grasses acres. The undercounting was due to estimated acres of underwater bay grasses with 'clipped' underwater bay grass beds within the GIS analyses. 'Clipped' areas represented the

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

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 grasses from a segment as viewed through the lens of GIS because the clipped underwater bay grasses 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 (see pp. 92-93).

To account for the underwater bay grasses acreages undercounting issues, "*The chosen solution 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 underwater bay grasses 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 partnership with two different sets of underwater bay grasses restoration 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 still lacking bathymetry data. This 'expanded restoration acreage' is being documented here and provided to the partners as the best acreage values that can be directly compared with SAV acreages reported through the bay-wide SAV aerial survey. These acreages are not the officially adopted goals of the watershed partners; they are for consideration by the jurisdictions when adopting refined and new water quality standards regulations.*
>
> *The Chesapeake Bay Program SAV restoration goal of 185,000 acres and the segment-specific goal acreages stand as the watershed partners' cooperative restoration goal for this critical living resource community (Chesapeake Executive Council 2003). EPA recommends that the jurisdictions with the Chesapeake Bay tidal waters consider*

adopting the expanded restoration acreages…into their refined and new water quality standards regulations."

There were also no bathymetric data for many tidally connected ponds in the Chesapeake Bay segments. Underwater bay grasses in these ponds, therefore, was excluded from these restoration 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 mapped underwater bay grasses, 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 restoration goal…acreages. This new information will also help the four jurisdictions with Chesapeake Bay tidal waters to adopt consistent, specific procedures for determining attainment of the shallow-water bay grass designated uses into their regulations. EPA continues to support and encourage the jurisdictions' adoption of segment-specific submerged aquatic vegetation (SAV) restoration goal acreages…necessary to support restoration of those acreages of SAV into each jurisdiction's respective water quality standards regulations."

After the 185,000 acre restoration goal was set, 2002 data for underwater bay grass aerial surveys became available to support decision-making for establishing the four jurisdictions' Chesapeake Bay water quality standards.

WATER QUALITY STANDARDS-BASED UNDERWATER BAY GRASSES RESTORATION ACREAGES

The Chesapeake Bay Program's Submerged Aquatic Vegetation Workgroup, working with Chesapeake Bay Program Office staff, determined that the basis for the 185,000 acre goal formed the foundation for the water quality standards-based goal. With few exceptions, the jurisdictions' Chesapeake Bay water quality standards segment-specific underwater bay grasses restoration acreages are equal to or greater than the segment-specific acreage goals supporting the original 185,000 acre goal (Table V-1). In setting the original underwater bay grasses restoration acreages back in 1993, the Partnership reached agreement on a methodology for derivation of the acreages which was applied consistently across all Chesapeake Bay segments.

In amending their state water quality standards regulations, however, Virginia made the decision in 2005 to adjust the Partnership's underwater bay grasses restoration acreages for four segments — three in the tidal James River and one in the lower Rappahannock River based on attainability considerations using model simulated outcomes. This was not the standard approach, but rather an internal state decision specific to handful of tidal Bay segments. EPA supported Virginia decisions as they were made on the best available information at that time and reflected Virginia concerns about their ability to reduce nutrient and sediment pollutant loads down to levels necessary to restore underwater bay grasses to the restoration acreages based on historical coverage.

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 grasses 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).

For purposes of water quality standards adoption and assessment of criteria attainment, the Chesapeake Bay and its tidal tributaries and embayments have been sub-divided into a total of 104 segments, including individual segments split by jurisdiction (U.S. EPA 2004, 2008). Of these 104 segments, there were 71 segments[1] where the jurisdictions' Chesapeake Bay water quality standards underwater bay grasses restoration acreages were greater than the actual 1993 CBP underwater bay grasses restoration goal acreages and 22 segments[2] where the acreages were the same. Only in 11 segments[3] were the jurisdictions' Chesapeake Bay water quality standards underwater bay grasses restoration acreages revised to be lower than the original 1993 CBP underwater bay grasses restoration goal acreages. The rationale for these differences between the 1993 Chesapeake Bay Program's restoration goal acreages and the four jurisdictions Chesapeake Bay water quality standards underwater grasses restoration acreages are documented in Table V-2.

For the 11 segments where the jurisdictions' water quality standards acreages were lower than the original 1993 goal acreages, 7 of those segments were split segments. In all 7 of those split segments, the total sum of the individual split segments was equal to or higher than the original 1993 goal acreage for the entire segment. Therefore, only in the case of the four Virginia segments listed above were the water quality standards acreages lower than the 1993 goal acreages.

Table V-2. **Chesapeake Bay segment jurisdiction-specific water quality standards-based underwater bay grasses (SAV) restoration acreages compared with the original 1993 Chesapeake Bay Program SAV restoration goal acreages.**

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
Delaware								
C&DOH-DE	No Goal	NA	0	-	-	-	-	Source: Rebecca Golden, Maryland Department of Natural Resources, Pers. Comm.
NANTF-DE	No Goal	NA	-	-	-	-	-	-
District of Columbia								
ANATF-DC	1991	6	6	0	7	12	15	No Change
POTTF-DC	1991	368	383	15	376	383	383	Used Single Best Year (1991)
Maryland								
ANATF-MD	No Goal	NA	0	-	-	-	-	Source: Rebecca Golden, Maryland Department of Natural Resources, Pers. Comm.
BACOH	No Goal	NA	30	30	-	-	-	Goal target source is MD COMAR 26.08.02.03-3 regulations. Goal last updated November 2010 (Source: Rebecca Golden, Maryland Department of Natural Resources, Pers. Comm.)
BIGMH1	Historical	1,991	2,021	30	2,021	2,187	2,187	Total SAV Acreage Out to Split Segment's Application Depth (accounting for previously clipped acres). Note the total acres for sum of the split segments goals for BIGMH1 and BIGMH2 is greater than acreages of BIGMH before the split which affected separate application depths for the two sub-segments.

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
BIGMH2	Historical	23	22	-1	25	25	25	Total SAV Acreage Out to Split Segment's Application Depth (accounting for previously clipped acres). Note the total acres for sum of the split segments goals for BIGMH1 and BIGMH2 is greater than acreages of BIGMH before the split which affected separate application depths for the two sub-segments.
BOHOH	2000	97	354	257	112	187	354	Used Single Best Year (2001)
BSHOH	Historical	158	350	192	167	236	350	Used Single Best Year (2002)
C&DOH-MD	1978	0	7	7	-	-	7	Used Single Best Year (2001)
CB1TF1	Historical	833	754	-79	862	874	874	Total SAV Acreage Out to Split Segment's Application Depth (accounting for previously clipped acres). Note the total acres for sum of the split segments goals for CBTF1 and CBTF2 is approximately the total for CBTF1 before the split which is affected separate application depths for the two sub-segments.
CB1TF2	Historical	12,075	12,149	74	12,149	12,354	12,354	Historical Restoration Acreage + Clipped Acreage which equals Total SAV Acreage Out to Split Segment's Application Depth (accounting for previously clipped acres). Note the total acres for sum of the split segments goals for CBTF1 and CBTF2 is approximately the total for CBTF1 before the split which is affected separate application depths for the two sub-segments.
CB2OH	Historical	302	705	403	327	1,010	1,010	Used Single Best Year (2000)
CB3MH	1978	943	1,370	427	1,018	1,370	1,370	Used Single Best Year (1978)
CB4MH	Historical	2,511	2,533	22	2,533	2,824	2,824	Historical Restoration Acreage + Clipped Acreage

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
CB5MH-MD	Historical	8,257	8,270	13	8,270	8,575	8,575	Historical Restoration Acreage + Clipped Acreage
CHOMH1	Historical	8,044	8,184	140	8,184	8,721	8,721	Historical Restoration Acreage + Clipped Acreage
CHOMH2	Historical	1,499	1,621	122	1,621	2,020	2,020	Historical Restoration Acreage + Clipped Acreage
CHOOH	Historical	63	72	9	72	89	89	Historical Restoration Acreage + Clipped Acreage
CHOTF	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
CHSMH	Historical	2,724	2,928	204	2,928	3,762	3,762	Historical Restoration Acreage + Clipped Acreage
CHSOH	Historical	63	77	14	77	117	117	Historical Restoration Acreage + Clipped Acreage
CHSTF	No Goal	NA	1	1	-	-	-	Goal target source is MD COMAR 26.08.02.03-3 regulations. Goal last updated November 2010 (Source: Rebecca Golden, Maryland Department of Natural Resources, Pers. Comm.)
EASMH	Historical	6,108	6,209	101	6,209	6,397	6,397	Historical Restoration Acreage + Clipped Acreage
ELKOH1	2000	1,593	1,844	251	1,631	1,652	1,844	Used Single Best Year (2001)
ELKOH2	2000	55	190	135	57	57	190	Used Single Best Year (2001)
FSBMH	Historical	193	197	4	197	730	730	Historical Restoration Acreage + Clipped Acreage
GUNOH1	2000	1,772	1,860	88	1,833	1,860	1,860	Used Single Best Year (2000)
GUNOH2	2000	482	572	90	549	572	572	Used Single Best Year (2000)

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
HNGMH	Historical	7,686	7,761	75	7,761	7,943	7,943	Historical Restoration Acreage + Clipped Acreage
LCHMH	Historical	3,950	4,076	126	4,076	4,134	4,134	Historical Restoration Acreage + Clipped Acreage
MAGMH	Historical	545	579	34	579	716	716	Historical Restoration Acreage + Clipped Acreage
MANMH1	Historical	4,264	4,294	30	4,294	4,331	4,331	Historical Restoration Acreage + Clipped Acreage
MANMH2	Historical	95	59	-36	103	103	103	Total SAV Acreage Out to Split Segment's Application Depth. Note the total acres for the sum of the split segments goals for MANMH1 and MANMH2 is approximately the total for the MANMH before the split.
MATTF	2000	279	792	513	296	331	792	Used Single Best Year (2002)
MIDOH	Historical	838	879	41	879	910	910	Historical Restoration Acreage + Clipped Acreage
NANMH	Historical	3	3	0	3	6	6	No change
NANOH	Historical	3	12	9	12	13	13	Historical Restoration Acreage + Clipped Acreage
NANTF-MD	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
NORTF	Historical	88	89	1	89	164	164	Historical Restoration Acreage + Clipped Acreage
PATMH	Historical	298	389	91	389	585	585	Historical Restoration Acreage + Clipped Acreage

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
PAXMH1	Historical	1,148	1,459	311	1,183	1,474	1,474	Total SAV Acreage Out to Split Segment's Application Depth accounting for clipped acreage. Note the total sum of Water Quality Standards sub-segment acreage goal that represents PAXMH is greater than the original restoration goal
PAXMH2	Historical	172	172	0	192	201	201	Historical (USEPA Oct. 2004). No Change
PAXMH3	Historical	0	0	0	-	-	282	Historical (USEPA Oct. 2004). No Change
PAXMH4	Historical	2	1	-1	2	3	348	Total SAV Acreage Out to Split Segment's Application Depth accounting for clipped acreage. Note the total sum of Water Quality Standards sub-segment acreage goal that represents PAXMH is greater than the original restoration goal
PAXMH5	Historical	3	2	-1	3	7	378	Total SAV Acreage Out to Split Segment's Application Depth accounting for clipped acreage. Note the total sum of Water Quality Standards sub-segment acreage goal that represents PAXMH is greater than the original restoration goal
PAXMH6	Historical	0	0	0	-	-	82	Historical (USEPA Oct. 2004). No Change
PAXOH	2000	68	115	47	104	115	115	Used Single Best Year (2000)
PAXTF	1996	5	205	200	152	158	205	Used Single Best Year (2001)
PISTF	1987	783	789	6	788	788	789	Used Single Best Year (1987)

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
POCMH-MD	Historical	859	877	18	877	912	912	Historical Restoration Acreage + Clipped Acreage
POCOH-MD	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
POCTF	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
POTMH-MD	Historical	6,919	7,088	169	7,088	9,005	9,005	Historical Restoration Acreage + Clipped Acreage
POTOH1-MD	1998	1,306	1,387	81	1,363	1,387	1,387	Used Single Best Year (1998)
POTOH2-MD	1998	226	262	36	262	262	262	Used Single Best Year (1998)
POTOH3-MD	1998	1,044	1,153	109	1,150	1,153	1,153	Used Single Best Year (1998)
POTTF-MD	1991	1,992	2,142	150	2,063	2,143	2,143	Used Single Best Year (1991)
RHDMH	Historical	48	60	12	60	98	98	Historical Restoration Acreage + Clipped Acreage
SASOH1	2000	763	1,073	310	814	958	1,073	Used Single Best Year (2001)
SASOH2	2000	1	95	94	2	95	1,938	Used Single Best Year (2001)
SEVMH	1999	329	455	126	351	455	455	Used Single Best Year (1999)
SOUMH	Historical	459	479	20	479	552	552	Historical Restoration Acreage + Clipped Acreage
TANMH1	Historical	24,451	24,683	232	24,675	26,250	26,250	Total SAV Acreage Out to Split Segment's Application Depth accounting for clipped acres. Note the total acres for the sum of the split segments goals for TANMH1 and TANMH2 is higher than the total for TANMH before the split.
TANMH2-MD	Historical	164	74	-90	165	166	166	Total SAV Acreage Out to Split Segment's Application Depth accounting for clipped acres. Note the total acres for the sum of the split segments goals for TANMH1 and TANMH2 is higher than the total for TANMH before the split.

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
WBRTF	No Goal	NA	0	-	-	-	-	No data or no evidence of SAV (USEPA Oct. 2004)
WICMH	Historical	3	3	0	3	7	7	No change
WSTMH	Historical	214	238	24	238	338	338	Historical Restoration Acreage + Clipped Acreage
Virginia								
APPTF	Historical	319	379	60	345	379	379	Historical Restoration Acreage + Clipped + No Depth Limitation
CB5MH-VA	Historical	6,704	7,633	929	6,779	7,633	7,633	Historical Restoration Acreage + Clipped + No Depth Limitation
CB6PH	Historical	980	1,267	287	1,015	1,266	1,266	Historical Restoration Acreage + Clipped + No Depth Limitation
CB7PH	Historical	14,620	15,107	487	14,975	15,108	15,108	Historical Restoration Acreage + Clipped + No Depth Limitation
CB8PH	1996	6	11	5	6	11	11	Used Single Best Year (1996)
CHKOH	2000	348	535	187	461	535	535	Used Single Best Year (2000)
CRRMH	Historical	516	768	252	518	647	768	Used Single Best Year (2002)
EBEMH	No Goal	NA	-	-	-	-	-	-
ELIPH	No Goal	NA	-	-	-	-	-	-

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
JMSMH	Historical	531	200	-331	605	712	712	200 acres were derived as "attainable acres" developed from the May 2004 Chesapeake Bay Program Water Quality/Sediment Transport model confirmation run (Source: Lew Linker (USEPA) via Cindy Johnson (VADEQ)).
JMSOH	1998	7	15	8	15	15	15	Used Single Best Year (2001)
JMSPH	Historical	604	300	-304	615	693	693	300 acres were derived as "attainable acres" developed from the May 2004 Chesapeake Bay Program Water Quality/Sediment Transport model confirmation run (Source: Lew Linker (USEPA) via Cindy Johnson (VADEQ)).
JMSTF1	Historical	1,333	1,000	-333	1,409	1,530	1,530	WQS Acreage of unknown origin
JMSTF2	Historical	266	200	-66	372	375	375	WQS Acreage of unknown origin
LAFMH	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
LYNPH	1986	69	107	38	71	107	107	Used Single Best Year (1986)
MOBPH	Historical	15,096	15,901	805	15,395	15,901	15,901	Historical Restoration Acreage + Clipped + No Depth Limitation
MPNOH	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
MPNTF	1998	75	85	10	76	85	85	Used Single Best Year (1998)

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
PIAMH	Historical	3,256	3,479	223	3,310	3,480	3,480	Historical Restoration Acreage + Clipped + No Depth Limitation
PMKOH	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
PMKTF	1998	155	187	32	158	187	187	Used Single Best Year (1998)
POCMH-VA	Historical	3,233	4,066	833	3,342	4,066	4,066	Historical Restoration Acreage + Clipped + No Depth Limitation
POCOH-VA	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
POTMH-VA	Historical	3,254	4,250	996	3,575	4,250	4,250	Historical Restoration Acreage + Clipped + No Depth Limitation
POTOH1-VA	1998	1,145	1,503	358	1,485	1,503	1,503	Used Single Best Year (1998)
POTTF-VA	1991	2,008	2,093	85	2,082	2,093	2,093	Used Single Best Year (1991)
RPPMH	Historical	5,380	1,700	-3680	5,500	7,814	7,814	1700 acres were derived as "attainable acres" developed from the May 2004 Chesapeake Bay Program Water Quality/Sediment Transport model confirmation run (Source: Lewis Linker (USEPA) via Cindy Johnson VADEQ)
RPPOH	No Goal	NA	4	4	-	-	-	There were no data or record of SAV, however, a decision was made to provide the segment with an acreage target of 4 acres
RPPTF	2000	20	66	46	40	40	66	Used Single Best Year (2001)
SBEMH	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
TANMH1-VA	Historical	13,351	13,579	228	13,520	13,579	13,579	Historical Restoration Acreage + Clipped + No Depth Limitation

Chesapeake Bay Segment	Source of the 1993 CBP SAV Restoration Goal Acreages	1993 CBP SAV Restoration Goals Acreages	State Water Quality Standards SAV Restoration Acreages	Difference Between State WQ Standards Acreages and 1993 Restoration Goal	Actual Mapped SAV (up to 2000) Clipped to Application Depth	Actual Mapped SAV (up to 2000) Not Clipped	Actual Mapped SAV (including that mapped more recently than 2000) Not Clipped	Rationale for the Difference in the Acreage Between the 1993 Chesapeake Bay Program Restoration Goal and the State Water Quality Standards SAV Restoration Acreages
WBEMH	No Goal	NA	NGZ	-	-	-	-	Designated SAV No Grow Zone (NGZ)
YRKMH	Historical	176	239	63	187	239	239	Historical Restoration Acreage + Clipped + No Depth Limitation
YRKPH	Historical	2,272	2,793	521	2,297	2,766	2,766	2793 acres were derived as "attainable acres" developed from the May 2004 Chesapeake Bay Program Water Quality/Sediment Transport model confirmation run (Source: Lew Linker (USEPA) via Cindy Johnson (VADEQ)).
Totals (acres)	**-**	**184,892**	**191,921**	**-**	**189,863**	**206,776**	**211,084**	**-**

Key: NGZ = designated SAV no grow zone; NA = not applicable

Table V-2. Chesapeake Bay segments and their underwater bay grasses goal acreage changes from 1993 Chesapeake Bay Program restoration goal acres to 2004 water quality standards goal acres.

Segments with declines in goals acres	Segments with no change to the acreage	Segments with an increase in goal acres
BIGMH2, CB1TF1, MANMH2, PAXMH4, PAXMH5, TANMH2-MD, JMSTF1, JMSTF2, JMSMH, JMSPH, RPPMH	ANATF-DC, ANATF-MD, C&DOH-DE, CHOTF, NANTF-DE, NANTF-MD, NANMH, PAXMH2, PAXMH3, PAXMH6, POCOH, POCTF, WRBTF, WICMH, EBEMH, ELIPH, LAFMH, MPNOH, PMKOH, POCOH, SBEMH, WBEMH	POTTF-DC, BACOH, BIGMH1, BIGMH2, BOHOH, BSHOH, C&DOH-MD, CB1TF1, CB1TF2, CB2OH, CB3MH, CB4MH, CB5MH-MD, CHOMH1, CHOMH2, CHOOH, CHOTF, CHSMH, CHSTF, EASMH, ELKOH1, ELKOH2, FSBMH, GUNOH1, GUNOH2, HNGMH, LCHMH, MAGMH, MANMH1, MATTF, MIDOH, NANOH, NORTF, PATMH, PAXMH1, PAXOH, PAXTF, PISTF, POCMH-MD, POTMH-MD, POTOH1-MD, POTOH2-MD, POTOH3-MD, POTTF-MD, RHDMH, SASOH1, SASOH2, SEVMH, SOUMH, TANMH1, WSTMH, APPTF, CB5MH-VA, CB6PH, CB7PH, CB8PH, CHKOH, CRRMH, JMSOH, LYNPH, MOBPH, MPNTF, PIAMH, PMKTF, POCMH-VA, POTMH-VA, POTOH1-VA, POTTF-VA, RPPOH, RPPTF, TANMH1-VA, YRKMH, YRKPH.

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

In the 2014 *Chesapeake Bay Watershed Agreement*, the Chesapeake Bay Program partners adopted the 192,000 acres as the partnership's official underwater bay grasses 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 (Chesapeake Executive Council 2014). The 185,000 acre underwater bay grasses restoration goal was recognized by the Partnership as a conservative target affected by undercounting underwater bay grasses 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).

CONSIDERATIONS FOR FUTURE UNDERWATER BAY GRASSES RESTORATION ACREAGE GOALS

There are four Virginia segments – upper tidal fresh James River, lower tidal fresh James River, middle James River and Lower Rappahannock River – which are lower than the 1993 restoration goal acreage because they were based on model simulation attainability decisions. These acreages are inconsistent with the methodology used in all the other 100 segments in Virginia, Maryland, Delaware and the District of Columbia. Future consideration should be given to building in additional consistency within and between the four Chesapeake Bay jurisdictions in their methodologies for basis of setting their water quality standards' underwater bay grasses restoration goal acreages.

To address one inconsistency, all four jurisdictions would only go out to Chesapeake Bay segment-specific application depth (the Maryland method) or they would extend out to include the deep water acres of underwater bay grasses mapped beyond the segment specific application depth (the Virginia methodology). If, for example, Maryland adopted the Virginia methodology, then the additional deep water acres beyond the application depth in Maryland beyond their existing goal acreages would increase the 192,000 goal by about 14,000 acres.

Finally, recognize that there are still five Chesapeake Bay segments without goal acreages which are not designated as bay grass "no grow zones" (see the eighth column in Table V-1). The acreage total remains subject to goals being set for these remaining segments without restoration acreage goals at this time.

LITERATURE CITED

Batiuk, R. A., R. J. Orth, K. A. Moore, W. C. Dennison, J. C. Stevenson, L. W. Staver, V. Carter, N. B. Rybicki, R. E. Hickman, S. Kollar, S. Bieber, and P. Heasly. 1992. *Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis.* Annapolis, MD. CBP/TRS 83/92. 248 pp.

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

Chesapeake Executive Council 1989. *Submerged Aquatic Vegetation Policy for the Chesapeake Bay and Tidal Tributaries.* Annapolis, MD. July.

Chesapeake Executive Council. 1993. *Directive 93-9 Submerged Aquatic Vegetation Restoration Goals.* U.S. EPA. Annapolis, MD.

Chesapeake Executive Council. 2000. *Chesapeake 2000*. Chesapeake Bay Program, Annapolis, MD.

Chesapeake Executive Council. 2003. *Directive No. 03-02 Meeting the Nutrient and Sediment Reduction Goals*. Chesapeake Bay Program, Annapolis, MD.

Chesapeake Executive Council. 2014. *Chesapeake Bay Watershed Agreement*. Chesapeake Bay Program, Annapolis, MD.

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

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

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

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

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

chapter **vi**

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

BACKGROUND

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 using a Benthic-Index of Biotic Integrity (B-IBI) (see Appendix J in U.S. EPA 2007a). This chapter documents an interim rule for an assessment protocol supporting the two states' evaluation of Chesapeake Bay benthic community data as part of their 305(b)/303(d) Integrated Reports. This assessment protocol builds directly on the more detailed assessment methods recommended by Llansó et al. 2005 (see Appendix K in U.S. EPA 2007a).

Managers and practitioners of the B-IBI in the Chesapeake Bay Program partnership have found several Chesapeake Bay segments consistently classified as unimpaired while having degraded B-IBI scores coincident with high variability in the segment data informing those scores. The managers and practitioners, using best professional judgement, worked with U.S. EPA to use apply an interim rule that reclassified these special case assessment results into a regulatory Clean Water Act (CWA) 303(d) impairment listing of 'insufficient available data and/or information to make a use support determination'.

Coincident with the interim rule decision, a recalibration of the B-IBI was initiated in 2014 that was anticipated to support a more robust scoring of Chesapeake Bay segments, alleviating the need to apply the interim rule. A recalibrated B-IBI was anticipated to improve the decision support tool. However, in 2016, the recalibration efforts with the

B-IBI produced lower classification efficiencies (Llanso et al. 2016 – Appendix G in this document). The application of a revised B-IBI tool with new lower classification efficiencies was not supported by the Chesapeake Bay Program partners through a decision by the Chesapeake Bay Program's Criteria Assessment Protocol Workgroup. Therefore, the interim 303(d) listing rule for segments that follow the special case conditions noted by CBP partners during past assessments (i.e., B-IBI scores that suggest degraded conditions yet result in unimpaired status assignments affected by wide variability in the sample scores informing the B-IBI score) is recommended to remain in effect at this time.

REVIEW OF INDEX RECALIBRATION RESULTS

The annual Chesapeake Bay benthic macroinvertebrate community health assessment supports Maryland's and Virginia's tidal waters Clean Water Act 303(d) listing decisions for the Aquatic Life designated use. The assessments are separate from the Chesapeake Bay water quality criteria attainment assessment determinations. B-IBI results provide stand-alone or supplemental information for the two states to use in making their CWA Section 303(d) listing cycle decisions (U.S. EPA 2007). The application of the B-IBI 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 four Chesapeake Bay segments with what managers and practitioners considered conflicting results. The four segments 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 sample results (minimum sample size is 10 for an assessment) producing wide confidence intervals on the B-IBI segment assessment.

The CBP'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 mesohaline and polyhaline region (R. Llanso, VERSAR Inc., and D. Dauer, Old Dominion University, Personal Communication). In addition, some performance issues for determining the B-IBI scores have been identified throughout the years of its use (R. Llanso, VERSAR Inc., and D. Dauer, Old Dominion University, Personal Communication). The issues of concern have included:

1. When applied to small embayments, 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 and can be used today to calibrate the B-IBI for diagnostic purposes.

The Chesapeake Bay Program’s Criteria Assessment Protocol Workgroup recognized that most of these issues were under review. A B-IBI recalibration process was initiated in 2014. In order for Chesapeake Bay Program tidal water partners to make improved determinations about water quality status in the aquatic life use, interim rules were developed by the Criteria Assessment Protocol Workgroup and agreed by Maryland, Virginia, and EPA for application until the above issues are fully addressed through new research findings. Subsequently published updates to the B-IBI assessment protocol would be made available for adoption into the State’s Chesapeake Bay water quality standards.

This chapter recognizes this suite of issues of concern that are affecting the use of the Chesapeake Bay B-IBI in water quality status assignments of the tidal water aquatic life designated use. Interim decision rules to support a water quality status assignment to a segment assessment have been agreed upon between Maryland, Virginia and EPA. The rules are intended to be interim until new research provides a more robust B-IBI tool than the existing tool and is approved and adopted for use by the CBP partnership.

WATER QUALITY STATUS CLASSIFICATIONS

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

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.

Table VI-1. U.S. EPA's 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
Category 4a	A State developed TMDL has been approved by EPA or a TMDL has been established by EPA for any segment-pollutant combination.
Category 4b	Other required control measures are expected to result in the attainment of an applicable water quality standard in a reasonable period of time.
Category 4c	The non-attainment of any applicable water quality standard for the segment is the result of pollution and is not caused by a pollutant.
Category 5	Available data and/or information indicate that at least one designated use is not being supported or is threatened, and a TMDL is needed.

Source: Clean Water Act Section 303(d).

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

The below recommended interim decision rules address the most inconsistent, unreliable water quality status classifications output from the Chesapeake Bay B-IBI. To develop these 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 criterion 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., percent 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. Based on best professional judgement input from management practitioners using the B-IBI to support 303(d) listing decisions among the Chesapeake Bay state partners, the Chesapeake Bay Program's Criteria Assessment Protocol Workgroup used the difference of 0.5 B-IBI units between confidence interval limits on a segment score as a decision threshold for defining segments where the B-IBI score deserved further investigation. This magnitude of the confidence limit on the B-IBI was consistent with high variability in segments scores. Second, high variability coincident with a mean B-IBI score of 2.7 was used as a decision threshold because this value was the typical 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 303(d) listing classification results are "Impaired = No", Maryland and Virginia would identify those segments that also have a breadth of confidence limits ((Upper confidence Limit) – (Lower confidence Limit)) $\geq$ 0.5) of 0.5 or greater.

- Of that subset of segments with confidence limits $\geq$ 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 set of decision rules affects four Chesapeake Bay segments in the most recent 303(d) listing assessment. In Virginia, it affects the Corrotoman Mesohaline (CRRMH), South Branch Elizabeth River Mesohaline (SBEMH), and York River

Polyhaline (YRKPH). In Maryland, it affects the Sassafras River Oligohaline (SASOH). These four segments that have been previously considered unimpaired will now be classified as Category 3 in Maryland and Category 3B in Virginia (Table VI-2).

An update of the water quality standards classification table supporting decisions involving the aquatic life use in Chesapeake Bay water quality standards 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 assessments [1].

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

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

LITERATURE CITED

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

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

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

Llanso, R.J., D.M. Dauer, and M.F. Lane. 2016. *Chesapeake Bay B-IBI recalibration. August 2016 report to Virginia Department of Environmental Quality*. Deliverable to the U.S. EPA Chesapeake Bay Program. 31pp.

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

ACRONYMS

2-D	two-dimensional
ANATF	Anacostia Tidal Fresh
B-IBI	benthic index of biotic integrity
CBP	Chesapeake Bay Program
CIMS	Chesapeake Information Management System
CFD	cumulative frequency distribution
CHLA	chlorophyll *a*
CONMON	continuous monitoring
CRC	Chesapeake Research Consortium
DC	deep channel
DW	deep water
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
GLM	Generalized linear Model
HRSD	Hampton Roads Sanitation District
km^2	square kilometers
m	meters
mg/L	milligrams per liter
MRAT	Monitoring Realignment Action Team
NA	not applicable
NGZ	designated SAV no grow zone
OW	open water
PAXTF	Patuxent River Tidal Fresh
S	surface
SAS	Statistical Analysis Software
SAV	Submerged Aquatic Vegetation
SD	Standard Deviation
STAC	Scientific and Technical Advisory Committee
TMDL	Total Maximum Daily Load
VADEQ	Virginia Department of Environmental Quality
VIMS	Virginia Institute of Marine Science

APPENDIX A

Conditional Probability Analysis Support

The first section of this appendix 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 originally documented in the CBP STAC (2012) publication on the umbrella criteria assessment. The second section of this appendix 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.

CONDITIONAL PROBABILITY ANALYSIS BETWEEN THE 30-DAY AND 7-DAY MEAN DISSOLVED OXYGEN CONCENTRATIONS

Perry conducted a conditional probability analysis between the 30-day mean dissolved oxygen concentrations compared with the 7-day mean dissolved oxygen concentrations (see Appendix 2 in CBP STAC 2012) using high temporal density tidal 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 dissolved oxygen criterion would be satisfied and the 7-day mean dissolved oxygen criterion would be violated more than 10 percent of the time.

The method employed is based on the approach 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 mean dissolved oxygen criterion will be violated less than ten percent of the time if the 30-day mean dissolved oxygen criterion is being met (Figure A-1).

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 tidal Potomac River continuous monitoring locations (Table A-1, Figure A-2).

Table A-1. Names, locations, and years of continuous monitoring data used in this analysis.

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

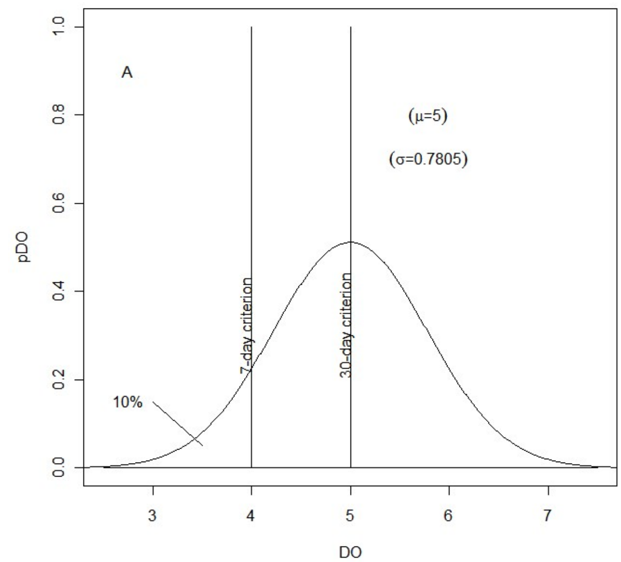

Figure A-1. Illustration of the level of variability of the 7-day mean about the 30-day mean that results in up to 10 percent violations of the 7-day mean dissolved oxygen criterion when the 30-day mean dissolved oxygen criterion is met.

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 dissolved oxygen concentration measurements for each month. Weekly means were computed as the arithmetic average of dissolved oxygen 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 (see 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 mean dissolved oxygen criterion given that the 30-day mean dissolved oxygen criterion was satisfied.

The results suggest that we would only see greater than 10 percent violations of the 7-day mean criterion given that they 30-day criterion is met if the 30-day mean were hovering at or just above the 30-day mean criterion. Because the 30-day mean rarely exhibits this behavior, it seems safe to conclude that in most cases the 30-day mean dissolved oxygen criterion acts to protect habitat under the 7-day mean dissolved oxygen criterion measure as well. However, slight increases in the variation of the

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

mean about the 30-day mean without corresponding increases in the 30-day mean could start to increase the violation rate for the 7-day criterion to above 10 percent.

Sampling Variability: Sampling Effort Effects the Mutual Criteria Attainment Assessment

As stated above, the Umbrella Criteria Assessment Team under the CBP Scientific, Technical Assessment and Reporting Team reviewed the variability of the 7-day mean dissolved oxygen about the 30-day mean dissolved oxygen and concluded that in general, that if the 30-day dissolved criterion is satisfied by the 30-day mean, then there is less than a 10 percent chance that the 7-day mean dissolved oxygen criterion will be violated by the 7-day mean dissolved 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 dissolved oxygen.

However, in many parts of the Chesapeake Bay and its tidal tributaries, 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 mean criterion for the 7-day mean 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 dissolved oxygen concentration time series records used are from the tidal Potomac River continuous monitoring data collected by the Chesapeake Bai Shallow-Water Water Quality Monitoring Program. For each calendar month in the May 1 through September 30 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 dissolved oxygen – monthly mean dissolved oxygen) for weeks that occur within a month. In all cases, the weekly mean dissolved oxygen 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 7-day mean about the 30-day 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 7-day mean is less than 4.0, the 7-day mean criterion, while the 30-day 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 dissolved oxygen 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 A-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 A-3).

Table A-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 A-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 A-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 A-3 and A-4.

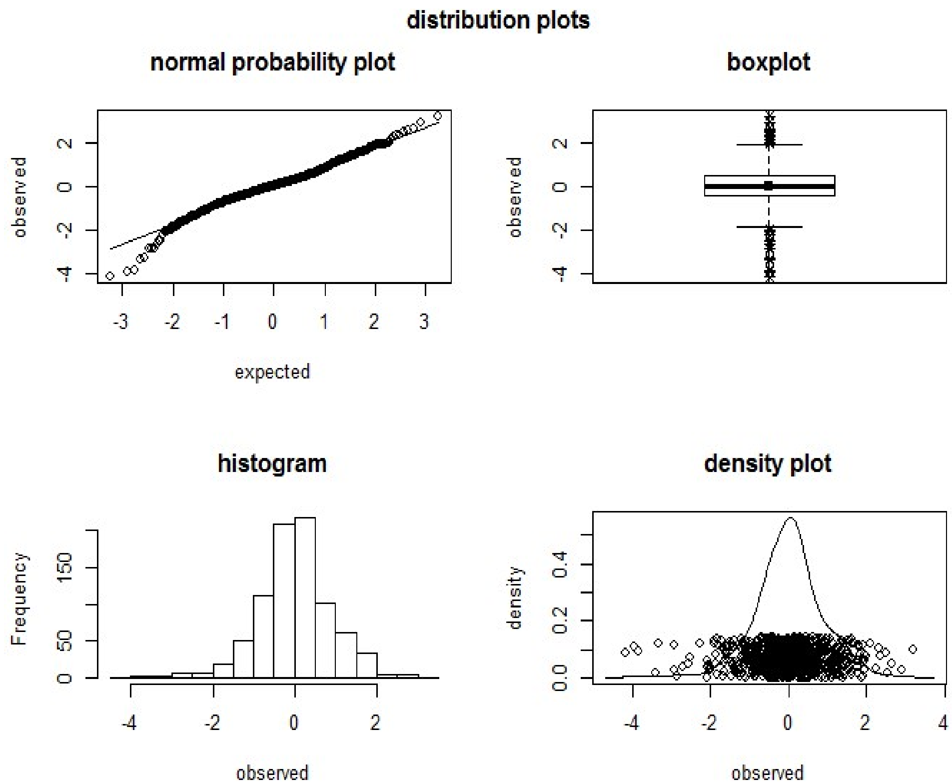

Figure A-3. Distribution plots for the true weekly deviations.

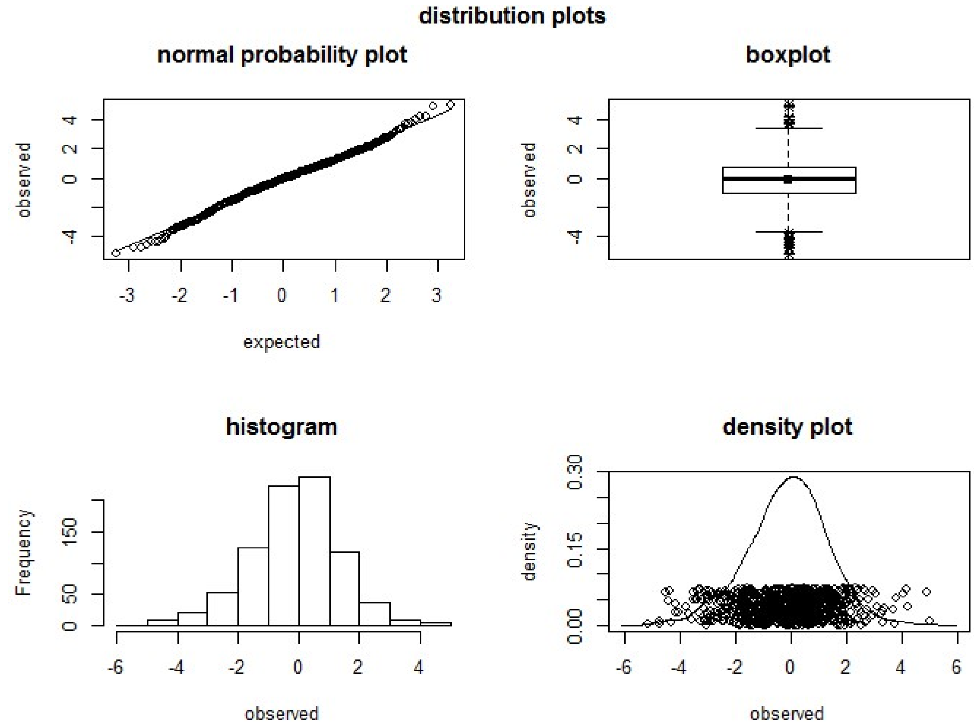

Figure A-4. Distribution plots for weekly deviations computed for the first resampling experiment.

Table A-3. Estimates of risk of violating the 7-day mean dissolved oxygen criterion given the monthly mean estimate (column 1) and four levels of sampling variation (columns 2-5) illustrating the risk of violating the 7-day mean dissolved oxygen criterion.

30-Day Mean Dissolved Oxygen Concentration	Risk of Violating 7-day Mean 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

Notes: Column 1 assumes near true weekly deviations, column 2 assumes variation for the average of 20 small sample estimates of the monthly mean, column 3 assumes variation at the minimum of the 20 small sample estimates of the monthly mean and column 4 assumes variation at the maximum of 20 small sample estimates of the monthly mean.

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.

A Parametric Simulation Approach to Assessing the Umbrella Concept for the Instantaneous Minimum Criterion

High frequency samples of dissolved oxygen at fixed locations show that there is considerable serial dependence or autocorrelation in these dissolved oxygen time series. This lack of independence makes it difficult to analytically compute the probability that an instantaneous minimum dissolved oxygen criteria will be violated when an umbrella criterion (e.g. 7-day or 30-day 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 dissolved oxygen time series. The data used for this exercise are the open-water buoy data compiled by Olson (see U.S. EPA 2004; Table C-1 in Appendix C this document). 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 Chesapeake Bay Segment CB4MH 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 VarianceCovariance matrix estimate from the MANOVA. Each of these 1000 realizations 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 dissolved oxygen criterion (3.2 mg/L) 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.

When examining data from all buoy locations, in a multivariate sense, all of these terms are statistically significant (Table A-4). Table A-5 shows which independent variables appeared to have an effect on which dependent variables. Table B-6 shows dissolved oxygen seems to improve as water depth increases, dissolved oxygen degrades as sensor depth increases, AR1 terms are stronger in the western bay and mse decreases with sensor depth.

Table A-4. 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 A-5. 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 A-6. 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

From Table A-7, 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).

Table A-7. 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

Using the manova model for Chesapeake Bay Segment CB4MH 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 dissolved oxygen is just greater than the 30-day mean criterion of 5.0 mg/L.

The independent variable vector that yields this prediction is:

May	June	July	Aug	Sept	Oct	Water Depth	Sensor Depth
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 dissolved oxygen criterion.

By changing the sensor depth of the independent variable vector, the long term 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 6 m to 3 m the mean dissolved oxygen concentration is increased from 5.0058 to 7.0082 mg/L (Table A-8). 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 A-8. Time series parameters sensitivity to changes in sensor depth.

Depth	Sensor b_Int	b_cday	b_sin	b_cos	b_AR1	_AR2	Mse
6	5.0058	-0.0493	-0.4072	-0.0527	0.9333	-0.0319	0.3164
5	5.6733	-0.0476	-0.5114	0.0094	0.9328	-0.0294	0.4112
4	6.3408	-0.0460	-0.6156	0.0714	0.9324	-0.0268	0.5060
3	7.0082	-0.0443	-0.7198	0.1335	0.9320	-0.0243	0.6008

To compare violation rates of the 7-day mean criterion and instantaneous minimum criterion, we cross tabulate cases where the 7-day mean is less than 4.0 mg/L against cases where the violation rate of the instantaneous minimum exceeds 10 percent in each 1-week time series.

Table A-9. Sensor depth with mean dissolved oxygen and criterion failure rates.

a)

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

b)

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

c)

Sensor Depth = 4 mean = 6.3408	7-day mean > 4.0	7-day mean < 4.0	marginal failure instantaneous minimum
failure Instantaneous minimum < 10%	747 75.84%	0 0%	747 74.7%
failure Instantaneous minimum > 10%	238 24.16%	15 100%	253 25.3%
marginal for failure of 7-day mean	985	15	1000

d)

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

When the long term mean dissolved oxygen is at a 'just passing' level, the simulation predicts that the 7-day mean criterion will be violated about 16.6 percent of the weeks (Table A-10). If the long term mean dissolved oxygen concentration increases to 5.7 mg/L, then we expected fewer than 5.5 percent of the weeks with failure of the 7-day mean 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.

Table A-10. Prediction of 7-day mean criterion failure rate.

	Sensor Depth			
	6	**5**	**4**	**3**
Monthly mean dissolved oxygen	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%

Looking the violations of the instantaneous minimum is not so encouraging. When the long term dissolved oxygen mean is 'just satisfied', the simulation predicts that the instantaneous minimum criterion exceedance rate will exceed 10 percent in about 47 percent of the weeks. Even when the long term mean dissolved oxygen is 7, the simulation predicts 18.5 percent of weeks will have an instantaneous minimum dissolved oxygen criterion exceedance rate in excess of 10 percent (Table A-10).

LITERATURE CITED

CBP STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee). 2012. *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*: Findings of the Umbrella Criterion Action Team, Tidal Monitoring and Analysis Workgroup. August 2012, STAC Publication. 12-02.

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

APPENDIX B

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.

CHESPEAKE 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 tidal 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 CB7PH and CB8PH 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 sub-segment specific water clarity application depths and SAV acreage restoration goals within 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 SAV and an area with little or no SAV was used to guide where the division boundary lines were drawn (U.S. EPA 2004b). In Virginia, the James River tidal fresh segment (JMSTF) was sub-divided into an upper segment (JMSTF2) and a lower segment (JMSTF1) for application of the new water clarity/SAV restoration acreage and chlorophyll *a* water quality criteria (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 (U.S. EPA 2003b). 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., >2 m in depth) and shallow-water habitats (e.g., <2 m in depth) are similar enough to ensure protection of both the open-water and shallow-water bay grasses designated uses with a single set of dissolved oxygen 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 within 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. Lyerly 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, Virginia on the Potomac River and Corsica River, Maryland).

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 segment for purposes of criteria attainment assessment (U.S. EPA 2007a).

RECOGNITION OF A THREE-ZONE APPROACH TO SUB-SEGMENTATION

The U.S. EPA (2003c) 305(b) guidance highlights a three 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 Chesapeake Bay Program’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 tidal tributaries (Boynton et al. 2014, Lyerly et al. 2014). This combination of new science provided 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) 305(b) 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 in 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 B-1).

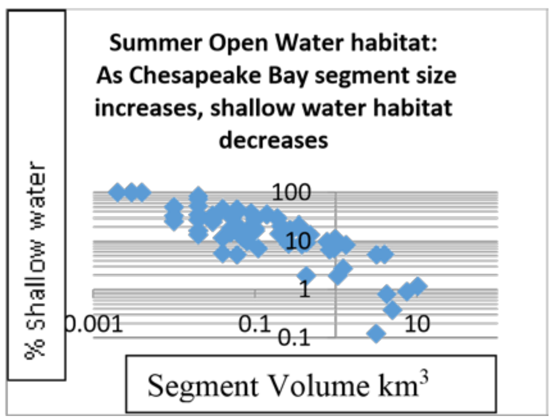

Figure B-1. The relationship of proportion of shallow-water habitat as it relates to the size of the Chesapeake Bay segments. Total segment volumes (km^3) were based on the U.S. EPA 2003b. Percent shallow water volumes were calculated from SAV Tier III acres (0-2m), converted to volume by assuming a 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 $\leq$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 km^2) less than or equal to 6 feet deep[4]. The total surface area of the tidal waters of Chesapeake Bay and its tidal tributaries and embayments is estimated to be 11,601 km^2. Therefore,

[4] http://www.chesapeakebay.net/discover/bay101/facts.

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 B-2)[5].

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 Chesapeake Bay TMDL (U.S. EPA 2010b). 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[6]), and Corsica River, MD (see Figure B-6).

Between 1987 and 2001, fish kill distributions in Maryland have been widespread and point to many areas over time where Maryland Department of the Environment attributed a portion of the observed fish kills potential causal effects may be due to hypoxia (Figure B-3). Mitigating the effects of nearshore hypoxia, therefore, has similar importance to the health of the Bay and its living resources as correcting deep water hypoxia issues due to its representative volume and area.

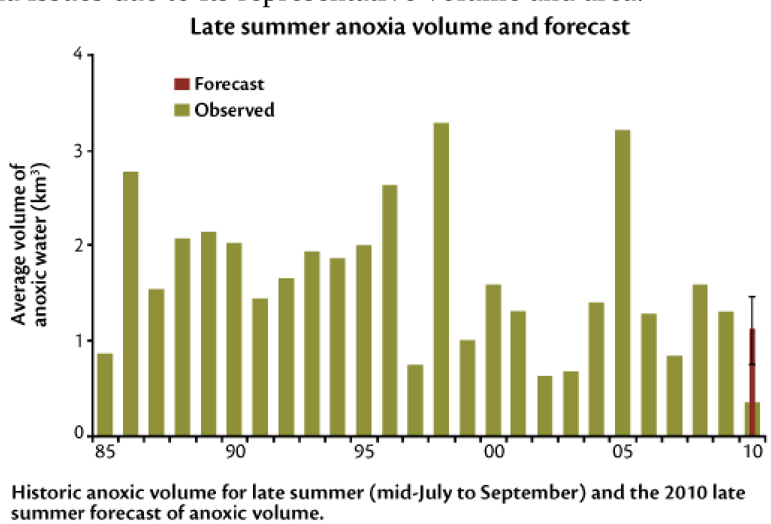

Figure B-2. Historical time series of anoxic volume for late summer also showing the 2010 IAN Ecocheck forecast. Source: http://ian.umces.edu/ecocheck/

[5] http://ian.umces.edu/ecocheck/summer-review/chesapeake-bay/2010/indicators/anoxia/.
[6] http://ian.umces.edu/pdfs/ian_report_card_212.pdf.

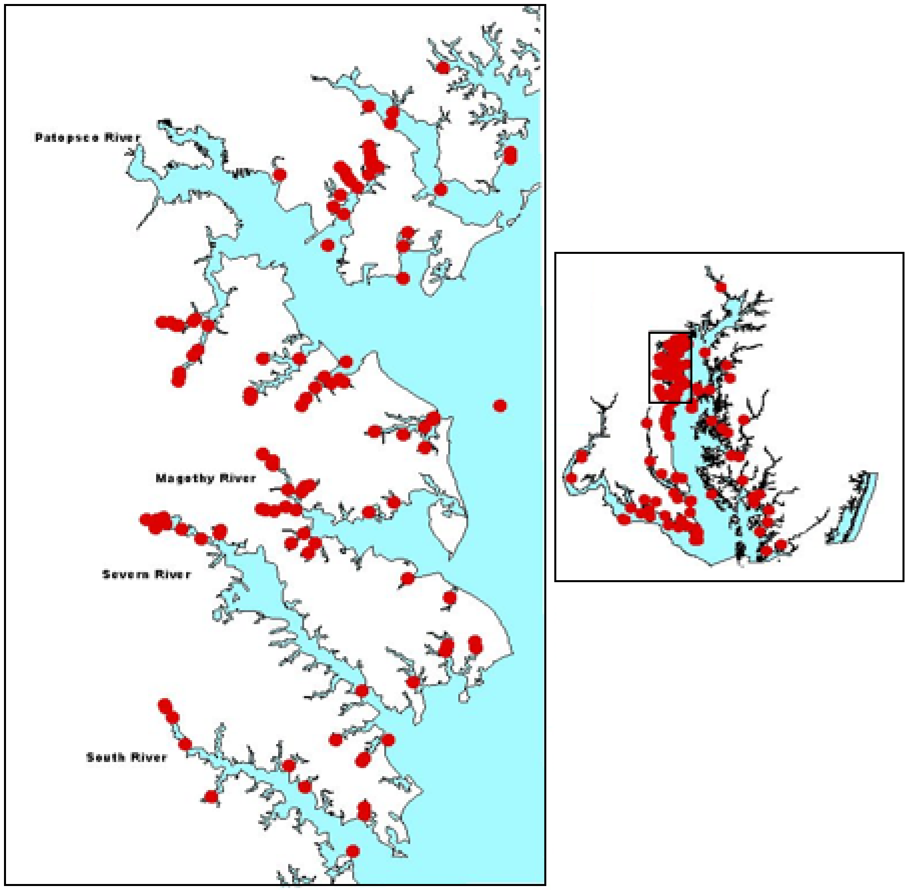

Figure B-3. Fish kills attributed to low dissolved oxygen Chesapeake Bay, Maryland, upper western shore area, 1987-2001.

Sources: Maryland Department of Environment Fish Kill Investigation Section, Fish Kill Database.

HISTORICAL REVEW OF THE COMPARABILITY OF NEARSHORE AND OFFSHORE WATER QUALITY IN CHESAPEAKE BAY

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's Chesapeake Bay Mainste and Tidal Tributaries 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 tidal tributaries (U.S. EPA 2007a). However, all these studies focused on parameters important to SAV 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 2003 *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 (U.S. EPA 2003a). 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 CBP's Chesapeake Bay Monitoring Realignment Action Team (MRAT 2009) and the CBP's Umbrella Criteria Assessment Team (CBP STAC 2012).

CHARACTERISTICS OF CHESPEAKE BAY HIGH FREQUENCY DISSOLVED OXYGEN DYNAMICS WITH 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 B-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 Chesapeake Bay aquatic life at or just after sunrise (see also Boynton et al. Appendix 4 in CBP-STAC 2012, U.S. EPA 2007a).

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 B-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 B-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.

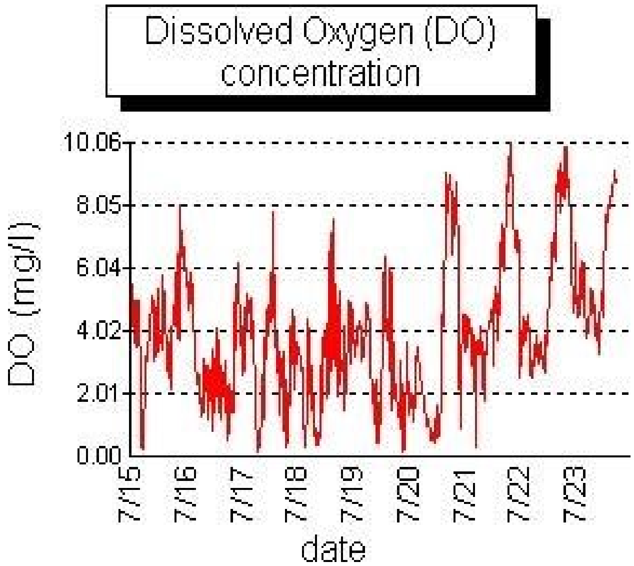

Figure B-4. Ben Oaks, Severn River, MD example of diel hypoxia in shallow water with data collected every 15 minutes.

Source: Maryland Department of Natural Resources

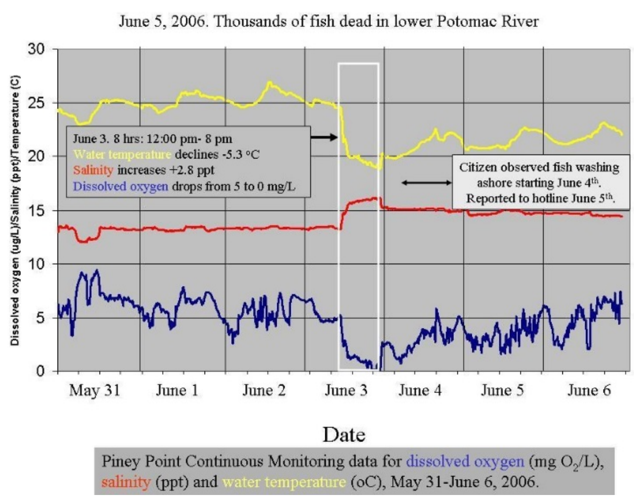

Figure B-5. Lower Potomac River Piney Point Continuous Monitoring data, Maryland Department of Natural Resources, from May 31 to June 6, 2006 shows intrusion of deeper water anoxic waters from the mainstem Chesapeake Bay. Such an intrusion affecting nearshore dissolved oxygen resources was linked with 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

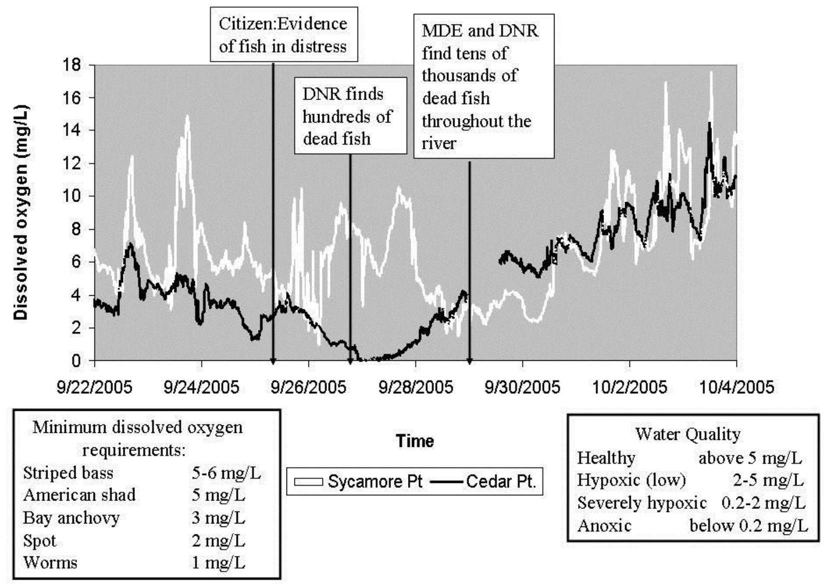

Figure B-6. Corsica River, MD, 2005. Chronology of a fish kill and associated water quality.

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/L, a summer range from 0.36-14.9 mg/L and an autumn range of 3.1-14.0 mg/L dissolved oxygen. The tidal Potomac River data further showed that the range of diel dissolved oxygen variability experienced in shallow waters reached 11.0 mg/L in spring, 17.52 mg/L in summer and 10.8 mg/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).

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

Based on the Chesapeake Bay Program Umbrella Criteria Assessment Team's 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 Chesapeake Bay Program 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) 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) provides additional insights into Robertson's (2013) findings regarding differences in dissolved oxygen patterns at the shortest (daily or less) time scales. Trice (2013) compared 2004 and 2005 summer season hourly average data for co-located monitoring stations of Pin Oak (nearshore) and CBL (offshore) on the lower tidal Patuxent River (Figure C-7). 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.

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) found 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.

Thes findings are consistent with the 3-zone approach recommended in U.S. EPA (2003) 305(b) 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) 305(b) 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 a logical 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).

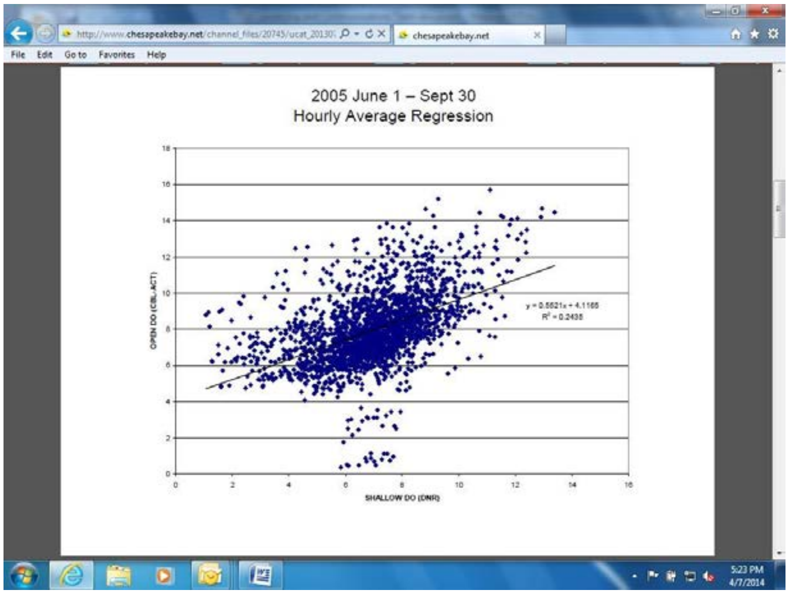

Figure B-7. 2005 example of hourly average comparisons illustrating the tendency for nearshore shallow water conditions to be lower than offshore, Patuxent River.

Source: Maryland Department of Natural Resources

LITERATURE CITED

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

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

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

CBP STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee). 2012. *Evaluating the Validity of the Umbrella Criterion Concept for Chesapeake Bay Tidal Water Quality Assessment*: Findings of the Umbrella Criterion Action Team Tidal Moni toring and Analysis Workgroup (TMAW) August 2012, STAC Publ. 12-02.

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

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

Lyerly C.M., A.L. Hernandez Cordero, K.L. Foreman, S.W. Phillips, W.C. Dennison. 2014. New insights: science-based evidence of water quality improvements, challenges and opportunities in the Chesapeake.

Trice, M. 2013 http://www.chesapeakebay.net/calendar/event/20745/ July 12, 2013 Umbrella Criteria Action Team, Shallow water vs. Open Water Dissolved Oxygen (DO). Power point presentation.

Robertson, T. 2013. http://www.chesapeakebay.net/calendar/event/20745/ July 12, 2013 Umbrella Criteria Action Team, Nearshore vs. Offshore York and Rappahannock. Power point presentation.

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

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

U.S. EPA (U.S. Environmental Protection Agency). 2003c. *Guidance for 2004 Listing and Reporting Requirements Pursuant to Sections 303(d) and 305(b) of the Clean Water Act, July 21, 2003.* U.S. Environmental Protection Agency Office of Water, Office of Wetlands, Oceans and Watersheds, Assessment and Watershed Protection Division, Watershed Branch, Washington D.C.

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

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

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

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

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

VA DEQ (Virginia Department of Environmental Quality). 2014. *Water Quality Assessment Guidance Manual for 2014 305(b)/303(d) Integrated Water Quality Report.* April 2014, Richmond, VA.

APPENDIX C

Chesapeake Bay Water Quality Data Supporting Development and Testing of Short-Duration Dissolved Oxygen Criteria Attainment Assessments

Quality assured, quality controlled water quality data sets were targeted by the Chesapeake Bay Program's Umbrella Criteria Assessment Team to conduct their method evaluations (Table C-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 dissolved oxygen 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 C-1. Data sources serving the umbrella criterion assumption analyses.

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

LITERATURE CITED

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

Environmental Protection Agency, Region III, Chesapeake Bay Program Office, Annapolis, MD.

APPENDIX D

Western Branch Patuxent River Tidal Freshwater Segment Metadata

This appendix contains data and metadata on the ten Western Branch Patuxent River Tidal Fresh (WBRTF) segment transects as reported by Maryland Department of the Environment. Water volumes are assigned to their segments and the data used to determine the volume assignment are provided here. Please note that only stations numbered 1-6 were located within the WBRTF segment. The segment starts from the southern bank of the river.

To compute the segment volume, the area of each cross-section was computed by an integration method. The volume between the two cross-sections is computed by multiplying the average of the two cross section area measurements and the distance between them. The total volume is the sum of all the volumes in the 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
Site description: 25 yards upstream of pier at Calvert Manor
Digital Photo Series: MD Department of Environment. Folder 113, images 1-2
Comments: 165 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	7.50	0
15	2.50	15.00	37.50
30	4.50	15.00	67.50
45	5.00	15.00	75.00
60	5.00	15.00	75.00
75	5.00	15.00	75.00
90	5.30	15.00	79.50
105	5.30	15.00	79.50
120	4.50	15.00	67.50
135	3.50	15.00	52.50
150	1.50	15.00	22.50
165	0	7.50	0

Sum of (depth*width) = area of streambed = 631.50 ft^2

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
Site description: 10 yards downstream of Horse Cavern Branch
Digital Photo Series: MD Department of Environment. Folder 113, images 3-5
Comments: 135 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	5.0	0
10	3.00	12.5	37.50
25	3.50	15.0	52.50
40	5.20	15.0	78.00
55	6.30	15.0	94.50
70	7.30	15.0	109.50
85	7.10	15.0	106.50
100	5.00	15.0	75.00
115	3.00	15.0	45.00
130	2.00	10.0	20.00
135	0	2.5	0

Sum of (depth*width) = area of streambed = 618.50 ft^2

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
Site description: No additional details.
Digital Photo Series: MD Department of Environment. Folder 113, images 6-8
Comments: 150 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	7.5	0
15	3.00	15.0	45.00
30	6.20	15.0	93.00
45	5.50	15.0	82.50
60	5.00	15.0	75.00
75	4.75	15.0	71.25
90	4.50	15.0	67.50
105	4.00	15.0	60.00
120	3.00	15.0	45.00
135	1.75	15.0	26.25
150	0	7.5	0

Sum of (depth*width) = area of streambed = 565.50 ft^2

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
Site description: downstream of small unnamed tributary
Digital Photo Series: MD Department of Environment. Folder 113, images 9-11
Comments: 135 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	5.0	0
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	5	0

Sum of (depth*width) = area of streambed = 481.13 ft^2

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
Site description: No additional details
Digital Photo Series: MD Department of Environment. Folder 113, images 12-13
Comments: 120 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	6.0	0
12	1.50	12.0	18.00
24	5.00	12.0	60.00
36	4.00	12.0	48.00
48	4.00	12.0	48.00
60	4.25	12.0	51.00
72	4.50	12.0	54.00
84	4.00	12.0	48.00
96	3.50	12.0	42.00
108	1.75	12.0	21.00
120	0	6.0	0

Sum of (depth*width) = area of streambed = 390.00 ft^2

River name: Western Branch   Station Code: Station #6   Date: 9/7/2001
Scientist(s): DJR/SGL   Riverbed Description: Sandy hard mud
Site location: N 38 47.832   W 76 43.746
Site description: 50 yards downstream of WSSC outfall
Digital Photo Series: MD Department of Environment. Folder 113, images 14-18
Comments: 66 feet wide, when measurements were taken there was a 1.5 foot high tide mark visible.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	2.5	0
5	4.00	7.5	30.00
15	4.50	12.5	56.25
30	5.25	10.0	52.50
35	6.00	5.0	30.00
40	6.50	5.0	32.50
45	7.50	5.0	37.50
50	8.00	5.0	40.00
55	4.00	5.0	20.00
60	3.00	5.5	16.50
66	0	3.0	0

Sum of (depth*width) = area of streambed = 315.25 ft^2

River name: Western Branch   Station Code: Station #7   Date: 9/7/2001
Scientist(s): DJR/SGL   Riverbed Description: hard mud
Site location: N 38 47.858   W 76 44.046
Site description: 700 yards upstream of effluent
Digital Photo Series: MD Department of Environment. Folder 113, images 19-21
Comments: 48 feet wide
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	3.0	0
6	4.25	6.0	25.50
12	4.50	6.0	27.00
18	5.00	6.0	30.00
24	5.00	6.0	30.00
30	5.25	6.0	31.50
36	5.25	6.0	31.50
42	4.50	6.0	27.00
48	0	3.0	0

Sum of (depth*width) = area of streambed = 202.50 ft^2

River name: Western Branch Station Code: Station #8 Date: 9/7/2001
Scientist(s): DJR/SGL Riverbed Description: Sandy hard mud
Site location: N 38 47.957 W 76 43.874
Site description: No additional details
Digital Photo Series: MD Department of Environment. Folder 113, images 22-24
Comments: 48 feet wide
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	2.5	0
5	2.50	7.5	18.75
15	3.25	7.5	24.38
20	3.50	7.5	26.25
30	4.50	10.0	45.00
40	4.00	7.5	30.00
45	3.00	4.0	12.00
48	0	1.5	0

Sum of (depth*width) = area of streambed = 156.38 ft^2

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
Site description: Rt 301 crossing
Digital Photo Series: MD Department of Environment. Folder 113, images 25-26
Comments: 47 feet wide, had to do the geometry off of the bridge.
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0	0	2.5	0
5	1.00	5.0	5.00
10	1.00	5.0	5.00
15	1.60	5.0	8.00
20	1.60	5.0	8.00
25	1.70	5.0	8.50
30	2.30	5.0	11.50
35	2.50	5.0	12.50
40	2.90	5.0	14.50
45	2.50	3.5	8.75
47	0	1.0	0

Sum of (depth*width) = area of streambed = 81.75 ft^2

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
Site description: no additional details
Digital Photo Series: N/A
Comments: 29.5 feet wide
Orientation: Looking downstream, the measurements were collected left to right.

Length (feet)	Depth (feet)	Cell width (feet)	Depth*width (feet^2)
0.5	0.10	0.25	0.03 Low bank
1	1.00	0.75	0.75
2	3.00	1.00	3.00 water's edge left bank
3	4.50	2.00	9.00
6	4.00	3.00	12.00
9	3.50	3.00	10.50
12	3.40	3.00	10.20
15	3.40	3.00	10.20
18	3.20	3.00	9.60
21	3.20	3.00	9.60
24	3.30	3.00	9.90
27	3.00	2.50	7.50 water's edge right bank
29	2,70	1.50	4.05
30	0.10	0.50	0.05 high bank

Sum of (depth*width) = area of streambed = 29.50 ft^2

Appendix E

Centroid Coordinates for Grid Cells Used to Define the Chesapeake Bay Western Branch Tidal Fresh Segment

The Chesapeake Bay Western Branch Patuxent River Tidal Fresh segment (WBRTF) is represented by 45 Cartesian grid cells, each with dimensions 50m x 50m. Table E-1 of this appendix provides the centroid coordinates for the 45 grid cells used to define the WBRTF segment. The coordinates are in the UTM Zone 18 NAD83 projection.

Table E-1. Centroid coordinates for the 45 grid cells used to define the Western Branch Tidal Fresh segment. The coordinates are in the UTM Zone 18 NAD83 projection.

Id	X	Y	Depth (m)
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

Accounting for the Segment*Designated Use*Criteria Combinations Used to Compute the Multi-metric Water Quality Standards Indicator

Table F1. Segment*designated use*criteria combinations for Chesapeake Bay and its tidal tributaries.

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

Middle Central Chesapeake Bay	CB4MH	MD	X	X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_MD	MD		X	X	X	X	
Lower Central Chesapeake Bay	CB5MH_VA	VA		X	X	X	X	
Western Lower Chesapeake Bay	CB6PH	VA		X	X		X	
Eastern Lower Chesapeake Bay	CB7PH	VA		X	X		X	
Mouth of the Chesapeake Bay	CB8PH	VA		X			X	
Chickahominy River	CHKOH	VA	X	X			X	
Mouth of the Choptank River	CHOMH1	MD	X	X			X	
Lower Choptank River	CHOMH2	MD	X	X			X	
Middle Choptank River	CHOOH	MD	X	X			X	
Upper Choptank River	CHOTF	MD	X	X				
Lower Chester River	CHSMH	MD	X	X	X	X	X	
Middle Chester River	CHSOH	MD	X	X			X	
Upper Chester River	CHSTF	MD	X	X			X	
Corrotoman River	CRRMH	VA	X	X			X	
Eastern Bay	EASMH	MD		X	X	X	X	
Eastern Branch Elizabeth River	EBEMH	VA		X				
Mouth of the Elizabeth River	ELIPH	VA		X				
Elk River, Upper	ELKOH1	MD	X	X			X	
Elk River, Lower	ELKOH2	MD					X	
Fishing Bay	FSBMH	MD	X	X			X	
Gunpowder River, Upper	GUNOH1	MD	X	X			X	
Gunpowder River, Lower	GUNOH2	MD					X	
Honga River	HNGMH	MD		X			X	
Lower James River	JMSMH	VA	X	X			X	X

Middle James River	JMSOH	VA	X	X			X	X
Mouth of the James River	JMSPH	VA		X			X	X
Upper James River	JMSTF1	VA	X	X			X	X
Upper James River	JMSTF2	VA	X	X			X	X
Lafayette River	LAFMH	VA		X				
Little Choptank River	LCHMH	MD		X			X	
Lynnhaven River	LYNPH	VA		X			X	
Magothy River	MAGMH	MD	X	X	X		X	
Manokin River, Lower	MANMH1	MD	X	X			X	
Manokin River, Upper	MANMH2	MD					X	
Mattawoman Creek	MATTF	MD	X	X			X	
Middle River	MIDOH	MD	X	X			X	
Mobjack Bay	MOBPH	VA		X			X	
Lower Mattaponi River	MPNOH	VA	X	X				
Upper Mattaponi River	MPNTF	VA	X	X			X	
Lower Nanticoke River	NANMH	MD	X	X			X	
Middle Nanticoke River	NANOH	MD	X	X			X	
Upper Nanticoke River	NANTF_DE	DE	X	X				
Upper Nanticoke River	NANTF_MD	MD	X	X				
Northeast River	NORTF	MD	X	X			X	
Patapsco River	PATMH	MD	X	X	X	X	X	
Lower Patuxent River, Lower	PAXMH1	MD	X	X	X		X	
Lower Patuxent River, Upper	PAXMH2	MD					X	
Lower Patuxent River, Mill Creek	PAXMH3	MD					X	
Lower Patuxent River, Cuckold Creek	PAXMH4	MD					X	
Lower Patuxent River, St. Leonard Creek	PAXMH5	MD					X	

Lower Patuxent River, Island Creek	PAXMH6	MD					X	
Middle Patuxent River	PAXOH	MD	X	X			X	
Upper Patuxent River	PAXTF	MD	X	X			X	
Piankatank River	PIAMH	VA		X			X	
Piscataway Creek	PISTF	MD	X	X			X	
Lower Pamunkey River	PMKOH	VA	X	X				
Upper Pamunkey River	PMKTF	VA	X	X			X	
Lower Pocomoke River	POCMH_MD	MD	X	X			X	
Lower Pocomoke River	POCMH_VA	VA	X	X			X	
Middle Pocomoke River	POCOH_MD	MD	X	X				
Middle Pocomoke River	POCOH_VA	VA	X	X				
Upper Pocomoke River	POCTF	MD	X	X				
Lower Potomac River	POTMH_MD	MD	X	X	X	X	X	
Lower Potomac River	POTMH_VA	VA	X	X	X	X	X	
Middle Potomac River, MD Mainstem	POTOH_VA	VA	X	X			X	
Middle Potomac River, MD Port Tobacco River	POTOH1_MD	MD	X	X			X	
Middle Potomac River, MD Nanjemoy Creek	POTOH2_MD	MD	X	X			X	
Middle Potomac River	POTOH3_MD	MD	X	X			X	
Upper Potomac River	POTTF_DC	DC	X	X			X	X
Upper Potomac River	POTTF_MD	MD	X	X			X	
Upper Potomac River	POTTF_VA	VA	X	X			X	
Rhode River	RHDMH	MD	X	X			X	
Lower Rappahannock River	RPPMH	VA	X	X	X	X	X	
Middle Rappahannock River	RPPOH	VA	X	X			X	
Upper Rappahannock River	RPPTF	VA	X	X			X	
Sassafras River, Lower	SASOH1	MD	X	X			X	

Sassafras River, Upper	SASOH2	MD					X	
Southern Branch Elizabeth River	SBEMH	VA		X	X			
Severn River	SEVMH	MD	X	X	X		X	
South River	SOUMH	MD	X	X	X		X	
Tangier Sound	TAHMH_VA	VA		X			X	
Tangier Sound, MD Main Body	TANMH1_MD	MD		X			X	
Tangier Sound, MD Deal Island to Mouth of Nanticoke River	TANMH2_MD	MD					X	
Western Branch Elizabeth River	WBEMH	VA		X				
Western Branch Patuxent River	WBRTF	MD	X	X			X	
Wicomico River	WICMH	MD	X	X			X	
West River	WSTMH	MD	X	X			X	
Middle York River	YRKMH	VA	X	X			X	
Lower York River	YRKPH	VA		X	X		X	
TOTAL Number of Segments by Designated Use & Applicable Criteria			**72**	**92**	**18**	**10**	**90**	**7**

Appendix G

Chesapeake Benthic Index of Biotic Integrity Recalibration Report

CHESAPEAKE BAY B-IBI RECALIBRATION

Prepared by

Principal Investigators:

Roberto J. Llansó* Versar, Inc.

Daniel M. Dauer ODU

Michael F. Lane ODU

VERSAR, INC.*

Ecological Sciences and Applications

9200 Rumsey Road, Columbia, Maryland 21045

OLD DOMINION UNIVERSITY

Department of Biological Sciences

Old Dominion University, Norfolk, Virginia 23529

Submitted to:

Cindy S. Johnson

Chesapeake Bay Monitoring Manager

Virginia Department of Environmental Quality

629 East Main Street

Richmond, Virginia 23219

BACKGROUND AND OBJECTIVES

The Chesapeake Bay Benthic Community Restoration Goals (Ranasinghe et al. 1994) and the Benthic Index of Biotic Integrity (B-IBI) by which goal attainment is measured (Weisberg et al. 1997), are today standard tools in management decision making. The B-IBI is used to assess and monitor trends in Chesapeake Bay health, report condition for impaired waters assessments under the Clean Water Act (305b reports), support ambient water quality criteria development and assessment, and characterize benthic condition in tributary basins to assist in setting restoration goals. The B-IBI was last validated for tidal freshwater and oligohaline habitats by Alden et al. in 2002. However, the paucity of data available at that time made the index less robust in the tidal freshwater and oligohaline regions than in the more saline habitats of the Bay. In addition, some performance issues have been identified throughout the years, such as: (1) correct classification efficiencies for the B-IBI seem to be lower than those of the initial calibration effort for some regions of the Bay, (2) differences in pollution indicative and sensitive taxa metrics have been identified among the different salinity habitats which may affect index performance, and (3) high biomass is a desirable property in low salinity regions but excess biomass in the B-IBI is scored as degraded and thresholds may need modification. Large datasets that were unavailable to Weisberg et al. can be used today to test the performance of the B-IBI for the various salinity habitats, and used to recalibrate the B-IBI.

In this study we used the data available to Weisberg et al. (1997) and new data assembled from multiple sources and programs that were conducted in Chesapeake Bay from 1994 to the present. The aim of the study was to re-evaluate the metric thresholds. Classification efficiencies of samples classified a priori by biological, physical, and contaminant data were computed on the original Weisberg et al. thresholds and new thresholds. In addition, the scoring procedure for the biomass metric was re-evaluated, from a current scoring system (1,3,5,3,1) in which low biomass values (below the lower restorative threshold) and high biomass values (above the upper restorative threshold) are considered degraded, to a modified scoring system (1,3,5) in which only low biomass values are considered degraded. The study considered single replicate and means of replicate data, and post-1997 data separately because during the course of the project it became apparent that benthic conditions in Chesapeake Bay had changed from conditions on which the original calibration effort was based. Validation assessments were conducted for the following threshold iterations:

1. Original thresholds
2. New thresholds based on data available to Weisberg et al. and new data
3. New thresholds as above and modified biomass procedure
4. New thresholds based on means of replicate samples

5. New thresholds based on means of replicate samples and modified biomass procedure
6. New threshold based on post-1997 data

Weisberg et al. (1997) classification efficiencies were in the 80-90% range, but classification efficiencies on new data were somehow lower (70-75% range) in a subsequent study (Llansó et al. 2009). The present study addresses the question of whether adjusting thresholds using a larger dataset than that available to Weisberg et al. (iterations 2-6 above) produce better classification efficiencies than the baseline (iteration 1). The results of these validation assessments will be taken as the basis for accepting or rejecting the new thresholds.

DATA ASSEMBLAGE

Source

The datasets in this study were assembled from multiple sources (Table 1) and in a variety of formats either from: (1) data files downloaded from Internet websites maintained by the collecting agencies; (2) archived databases maintained by the participants of this study; (3) direct delivery via email transfer from the collecting agencies; and (4) data entry/cut and paste from electronic or hard copy versions of project final reports (Table 1). All samples met a set of selection criteria based on series of limitations that excluded observations based on geographic location, season of collection, and compatibility of sample processing.

All data selected were located strictly within the latitude and longitude boundaries of Chesapeake Bay and its contiguous tidal tributaries and were collected within the B-IBI index period (Weisberg et al., 1997). This period typically extends from July 1st through September 30th in any given year; however, additional samples from the first two weeks of October were included in this study to allow for samples collected later in the season due to storm events or other issues. With the exception of Virginia's National Coastal Condition Assessment (NCCA) data, all samples were collected using a 440-cm^2 surface sampling area Young grab. Virginia's NCCA data were collected using two ponar grabs per sample for a total sample area of 495 cm^2. All samples were sieved through a 0.5-mm mesh screen, and the organisms identified to the lowest possible taxonomic level. A comparison study between the Young grab and double ponar grab sampling approach for the Virginia NCCA samples indicated no significant differences in B-IBI metrics or benthic community dominant species at multiple stations in multiple habitat types, indicating that these data were compatible for combined analyses in this study (Dauer and Lane, 2005). Finally, no data were deemed acceptable for inclusion into the database unless they were accompanied by bottom salinity and dissolved oxygen measurements, estimates of the percentage of sediment silt-clay, sediment metal and contaminant concentrations, and 10 or 20-day endpoint amphipod toxicity test results for either *Ampelisca abdita*, *Leptocheirus plumulosus* or

Hyallela azteca. This process resulted in a final dataset comprised of 1,831 samples (including replicates) collected at 1,051 separate sampling events throughout the length of the Chesapeake Bay tidal watershed.

Several websites in addition to those listed in Table 1 provided useful assistance in the construction of the final dataset. National Institute of Standards and Technology's website for CAS number searches was an extremely helpful tool for assisting with the standardization of chemical variable names and for help with using CAS numbers to identify chemical parameter names (and vice-versa) that were absent from data sets (see http://webbook.nist.gov/chemistry/cas-ser.html). The Integrated Taxonomic Information System website and the World Register of Marine Species were also helpful with resolving taxonomic issues (see http://www.itis.gov/ and http://www.marinespecies.org/about.php,respectively). Verification of station locations was made by visual inspection of maps created using freeware available at HamsterMap.com http://www.hamstermap.com/custommap.html.

Reference Site Selection

Prior to the calculation of new thresholds all sites were divided into two *a priori* stress categories, i.e. Degraded and Reference (non-degraded). Table 2 summarizes the Reference selection criteria for this study. All Reference site criteria needed to be met before a site could be classified as Reference while violation of only one of the criteria resulted in a site being classified as Degraded. If dissolved oxygen concentrations were greater than 3.0 ppm, no chemical contaminant concentration exceeded Long et al.'s (1995) effects range-median concentrations, no more than three chemical contaminants exceeded Long et al.'s (1995) effects range-low concentrations, the ERM quotient as defined by Hyland et al. (2003) did not exceed a value of 0.0440, and sediments were not toxic based on the amphipod toxicity test, sites were classified as Reference. Additionally samples with less than three species were classified as depauperate and therefore as being degraded under the assumption that some minimum number of species would be expected in reference conditions. These criteria were similar to those of previous studies (Weisberg et al. 1997; Van Dolah et al. 1999; Llansó, et al., 2002) but derived primarily from those of Llansó et al. (2009) with some modifications. Previous studies have included samples with toxicity tests conducted with *Ampelisca abdita*; however, this study has included many samples with survival endpoints for different species, specifically *Leptocheirus plumulosus* and *Hyallela azteca*.

Two thirds of the Reference dataset was randomly selected for the computation of new thresholds and scoring of metric and B-IBI values. This became the Calibration dataset. One third was reserved to conduct sensitivity and reliability tests, i.e., efficiencies based on a priori site impact classifications. This became the Validation dataset. The baseline, i.e., classification efficiencies based on the Weisberg et al. (1997) and Alden et al. (2002) thresholds, was conducted on the entire dataset, using both the Reference and Validation datasets.

Table 1. List of data sources and number of observations. An asterisk indicates that the probability-based monitoring program samples listed were combined with sediment chemistry data and sediment toxicity data that were collected separately as part of ambient sediment toxicity assessments for the Chesapeake Bay Program Ambient Toxicity Program.

Project	Time Period	Number of Samples	Source of Biological and Dissolved Oxygen Data	Source of Chemistry and Toxicity Data
Environmental Monitoring and Assessment Program Virginian Province Data (EMAP)	1990-1993	738	https://archive.epa.gov/emap/archive-emap/web/html/geographic.html	Same as Biological
Mid-Atlantic Integrated Assessment (MAIA)	1997-1998	370	Versar Inc.	Same as Biological
Chesapeake Bay Program Ambient Toxicity Program (AMTOX)	1997-2003	104	Versar Inc. and Old Dominion University Long-Term Databases	Data
National Oceanic and Atmospheric Administration National Status & Trends Program (NOAA NS&T)	1998-2001	191	https://products.coastalscience.noaa.gov/collections/ltmonitoring/nsandt/	Same as Biological
Maryland Chesapeake Bay Probability-Based Monitoring Program (MDRBP)*	1997-2010	55	www.chesapeakebay.net	AMTOX Reports
Virginia Chesapeake Bay Probability-Based Monitoring Program (VARBP)*	1997-2005	36	www.chesapeakebay.net	AMTOX Reports
National Coastal Condition Assessment (NCCA)	2005-2014	337	Donald Smith, Virginia Department of Environment Quality	Same as Biological
	Total	1831		

Table 2. Degraded and Reference site classification criteria based on number of species collected, dissolved oxygen, sediment chemistry, and sediment toxicity.

Criteria	Degraded	Reference
Number of Species Collected	≤3	>3
Bottom Dissolved Oxygen (psu)	≤2	>3
Effects Range Median Exceedances	Any	None
Effects Range Low Exceedances	>10	<3
Toxicity	<80% and significant difference from control	Not toxic
ERM Quotient	>0.044 (High and Very High Benthic Risk Level)	≤0.044 (Low to Medium Benthic Risk Level)

THRESHOLDS

Original Thresholds

Thresholds published in Weisberg et al. (1997) and Alden et al. (2002) were entered in the project database (Table 3) and used to score metrics and the B-IBI using current B-IBI protocols whenever data sources did not contain these data, or where the computations in these data sources were old (EMAP, MAIA) and did not employ the latest B-IBI methods.

Table 3. B-IBI thresholds derived by Weisberg et al. (1997) and further updated by Alden et al. (2002). Metrics: Shan = Shannon index, Abun = Abundance (#/m2), Bmas = Biomass (g AFDW/m2), OPA4 = Abundance of pollution indicative taxa (%), EQA4 = Abundance of pollution sensitive taxa (%), OPBM = Biomass of pollution indicative taxa (%), EQBM = Biomass of pollution sensitive taxa (%), CAAB = Abundance of carnivore and omnivores (%), DDAB = Abundance of deep-deposit feeders (%), OPA8 = Abundance of pollution indicative freshwater taxa (%), OPA = Abundance of pollution indicative oligohaline taxa (%), EQA8 = Abundance of pollution sensitive oligohaline taxa (%), SCOR = Tolerance Score, PCR = Tanypodinae to Chironomidae abundance ratio (%). Numbers after metric name indicate percentile threshold, 5th to 95th.

HABITAT	SHAN_05	SHAN_50	ABUN_05	ABUN_25	ABUN_75	ABUN_95	BMAS_05	BMAS_25	BMAS_75	BMAS_95
Tidal Freshwater			800	1,050	4,000	5,500				
Oligohaline			180	450	3,350	4,050				
Low Mesohaline	1.7	2.5	500	1,500	2,500	6,000	1	5	10	30
High Mesohaline Sand	2.5	3.2	1,000	1,500	3,000	5,000	1	3	15	50
High Mesohaline Mud	2	3	1,000	1,500	2,500	5,000	0.5	2	10	50
Polyhaline Sand	2.7	3.5	1,500	3,000	5,000	8,000	1	5	20	50
Polyhaline Mud	2.4	3.3	1,000	1,500	3,000	8,000	0.5	3	10	30

	OPA4_50	OPA4_95	EQA4_05	EQA4_50	OPBM_50	OPBM_95	EQBM_05	EQBM_50	CAAB_05	CAAB_50
Tidal Freshwater										
Oligohaline									15	35
Low Mesohaline	10	20	5	25			40	80		
High Mesohaline Sand	10	25	10	40					20	35
High Mesohaline Mud	20	50	10	30	5	30	30	60	10	25
Polyhaline Sand	10	40	25	50	5	15				
Polyhaline Mud	15	50	25	40	5	20	30	60	25	40

	DDAB_05	DDAB_50	DDAB_95	OPA8_50	OPA8_95	OPA_50	OPA_95	EQA8_05	EQA8_50	
Tidal Freshwater		70	95	39	87					
Oligohaline						27	95	0.2	26	
Low Mesohaline										

High Mesohaline Sand										
High Mesohaline Mud										
Polyhaline Sand	10	25								
Polyhaline Mud										

	SCOR_50	SCOR_95	PCR_05	PCR_50
Tidal Freshwater	8	9.35		
Oligohaline	6	9.05	64	17
Low Mesohaline				
High Mesohaline Sand				
High Mesohaline Mud				
Polyhaline Sand				
Polyhaline Mud				

New Thresholds

New thresholds were calculated for each metric using the Calibration dataset (Table 4). This dataset included data available to Weisberg et al. (EMAP data) as well as the new data specified in the data assemblage section of this report. Other threshold iterations included thresholds based on means of replicate samples, and thresholds based on post-1997 data, i.e., separating the older data (EMAP, MAIA) from the most current data (Ambient Toxicity, probability-based monitoring, NOAA NS&T, and NCCA).

Table 4. New thresholds derived with data assembled for this project, including data available to Weisberg et al. (EMAP data) and new data. See Table 3 for metric names and numbers after metric names.

HABITAT	SHAN_05	SHAN_50	ABUN_05	ABUN_25	ABUN_75	ABUN_95	BMAS_05	BMAS_25	BMAS_75	BMAS_95
Tidal Freshwater			1,409	2,864	6,773	9,817				
Oligohaline			432	1,318	3,977	16,318				
Low Mesohaline	1.5	2.4	750	1,886	3,682	11,932	0.128	0.445	1.6	6.2
High Mesohaline Sand	1.5	2.7	566	1,307	3,352	9,455	0.101	0.386	1.6	8.6
High Mesohaline Mud	1.6	2.7	523	1,068	2,318	5,999	0.143	0.303	0.909	1.8
Polyhaline Sand	1.4	3.2	909	1,778	4,932	9,591	0.119	0.505	5.1	14.9
Polyhaline Mud	1.6	3	682	1,776	6,175	9,636	0.202	0.524	2.3	33.7

	OPA4_50	OPA4_95	EQA4_05	EQA4_50	OPBM_50	OPBM_95	EQBM_05	EQBM_50	CAAB_05	CAAB_50
Tidal Freshwater										
Oligohaline									0	26.3
Low Mesohaline	5.5	71.7	0.94	18.3			4.4	26.8		
High Mesohaline Sand	16.3	75.8	0.72	22.3					3.4	23.2
High Mesohaline Mud	21.9	68.4	2	19.5	27.3	79	0.52	7.5	4.5	18.2
Polyhaline Sand	6.3	35.3	3.9	53.4	4.8	46.3				
Polyhaline Mud	19.9	73.1	5.7	33.8	16.5	62	0.57	20.6	2.8	29.7

	DDAB_05	DDAB_50	DDAB_95	OPA8_50	OPA8_95	OPA_50	OPA_95	EQA8_05	EQA8_50	
Tidal Freshwater		71	95.1	39	87					
Oligohaline						15.8	93.8	0	2.3	
Low Mesohaline										
High Mesohaline Sand										
High Mesohaline Mud										
Polyhaline Sand	0.16	20.3								
Polyhaline Mud										

	SCOR_50	SCOR_95	PCR_05	PCR_50
Tidal Freshwater	8.7	9.7		
Oligohaline	7.3	9.6	0	0
Low Mesohaline				
High Mesohaline Sand				
High Mesohaline Mud				
Polyhaline Sand				
Polyhaline Mud				

Comparison Among Thresholds

New thresholds derived with the reference dataset assembled for this project were lower than the original Weisberg et al. (1997) and Alden et al. (2000) thresholds for metrics for which low numbers indicate degraded conditions, and this difference was larger for the lower, 5^{th} percentile threshold. These metrics include Shannon index (Figure 1), abundance and biomass of pollution sensitive taxa (Figures 5 and 7), abundance of carnivore and omnivores (Figure 8), abundance of deep-deposit feeders (Figure 9, but see below), and abundance of pollution sensitive oligohaline taxa (Figure 10).

For metrics for which high numbers indicate degraded conditions, the new thresholds were higher than the original thresholds (Figures 4, 6, and 11), except for abundance of pollution indicative taxa in the Polyhaline Sand habitat. For pollution indicative taxa, this difference was larger for the upper, 95^{th} percentile threshold (Figures 4 and 6).

For abundance, for which low numbers and high numbers indicate degraded conditions, the new 5^{th} percentile threshold was lower than the original 5^{th} percentile threshold, and the new 95^{th} percentile threshold was higher than the original 95^{th} percentile threshold (Figure 2). This was true for the high salinity habitats, but for the low salinity habitats (Tidal Freshwater, Oligohaline, and Low Mesohaline), the new 5^{th} percentile threshold was *higher* than the original threshold (Figure 2).

For biomass, for which low numbers and high numbers also indicate degraded conditions in the current B-IBI, the new 5^{th} percentile threshold was lower than the original 5^{th} percentile threshold; however,

the new 95^{th} percentile threshold was much lower (not higher, as with abundance) than the original 95^{th} percentile threshold (Figure 3).

Deep-deposit feeder abundance is defined differently in the Polyhaline Sand habitat than in the Tidal Freshwater habitat. In the Polyhaline Sand habitat low numbers of deep-deposit feeders indicate degraded conditions whereas in the Tidal Freshwater, high numbers of deep-deposit feeders indicate degraded conditions. In the Tidal Freshwater habitat there was no difference between the new and the original thresholds for deep-deposit feeders (Figure 9). Also, in the same habitat there was little difference between the new 95^{th} percentile threshold and the original 95^{th} percentile threshold for pollution indicative taxa (Figure 10).

The above results can be interpreted as follows:

1. Lowered thresholds relative to those of Weisberg et al.'s effort indicate lower metric values in recent samples. Conversely, for metrics for which high numbers indicate degraded conditions, higher thresholds indicate higher metric values in recent samples.

2. Differences between the new and the original thresholds are larger at the 5th and 95th percentile thresholds than at the 25th, 50th, or 75th percentile thresholds, indicating increased depauperate conditions in Chesapeake Bay.
3. As thresholds are lowered (5th) or raised (95th), the number of samples in the validation dataset that score "1" for degraded conditions *decrease*, therefore increasing the B-IBI and giving the false impression that conditions in Chesapeake Bay have improved should these thresholds be adopted.
4. High biomass values (above restorative thresholds) have traditionally been viewed as indicating degraded conditions. However, lower values in recent samples for all biomass samples suggest that this concept needs revision.
5. The percentage of pollution tolerant organisms in the Tidal Freshwater (tubificid oligochaetes and many insect larvae) has not changed substantially in more recent samples, suggesting that conditions in this habitat have not changed.

As shown in the next section, classification efficiencies of the B-IBI using the new thresholds did not improve over the baseline or current condition using the Weisberg et al. (1997) and Alden et al. (2002) thresholds.

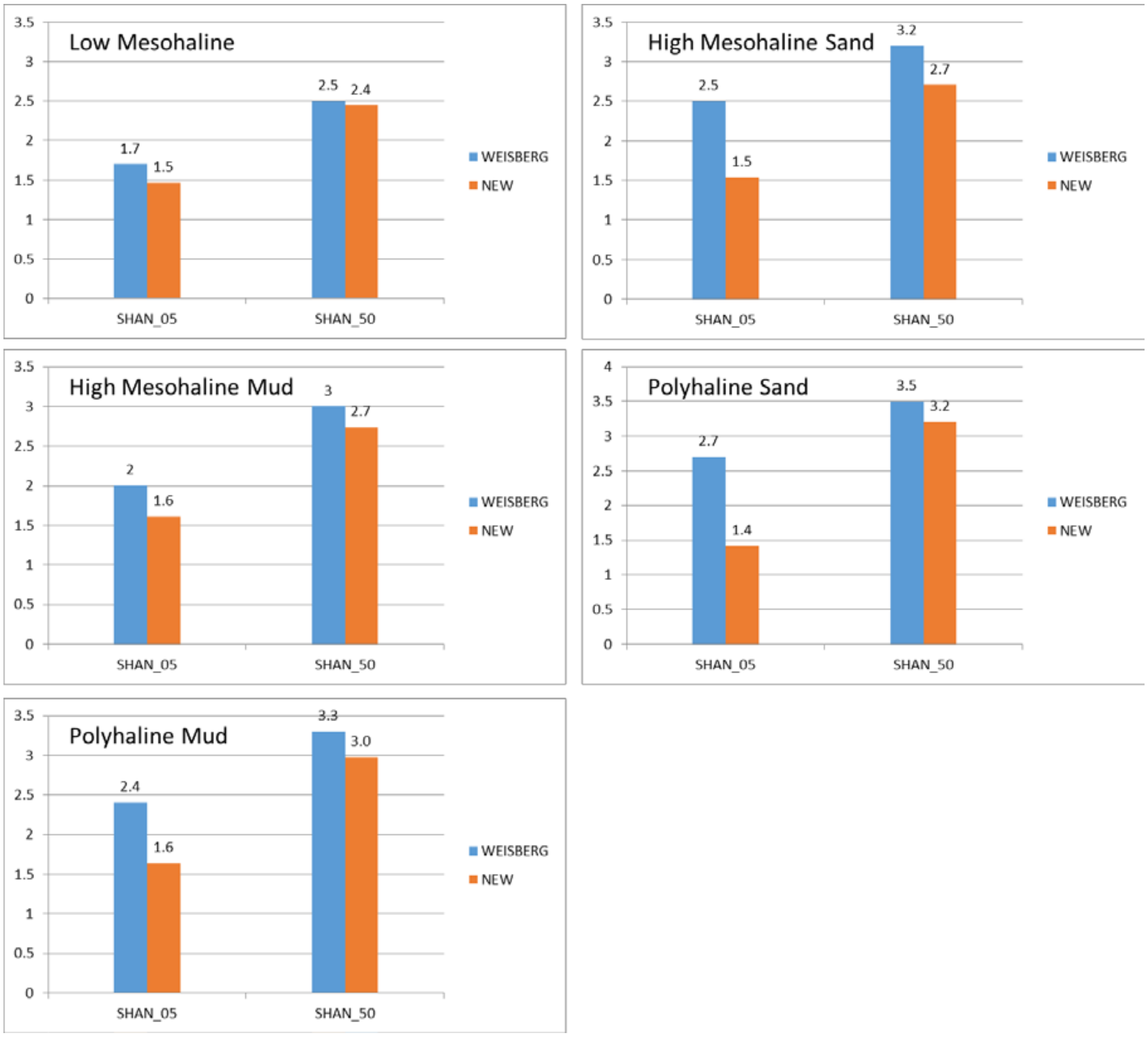

Figure 1. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for Shannon index (H').

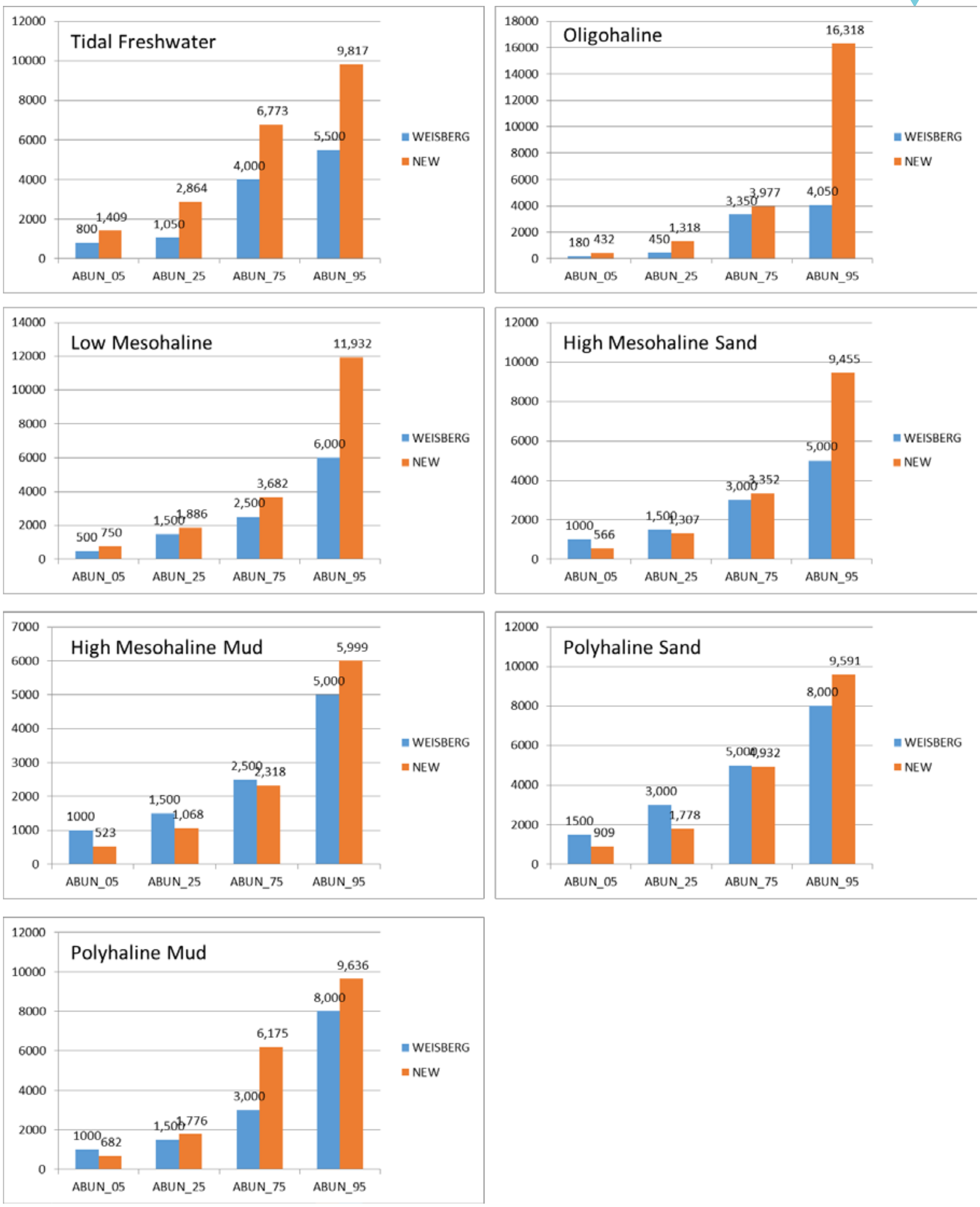

Figure 2. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance (#/m2).

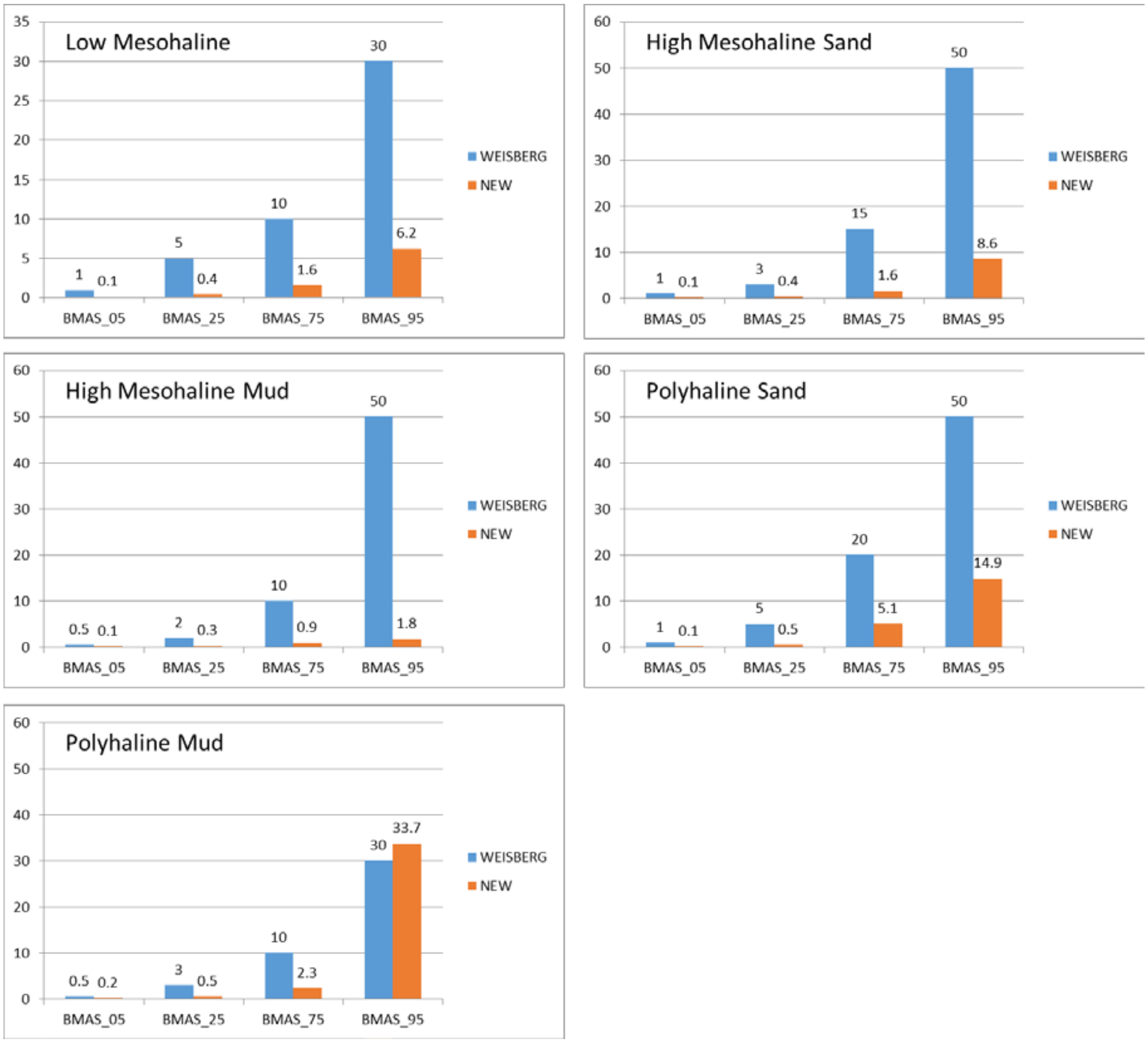

Figure 3. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for biomass (g AFDW/m2).

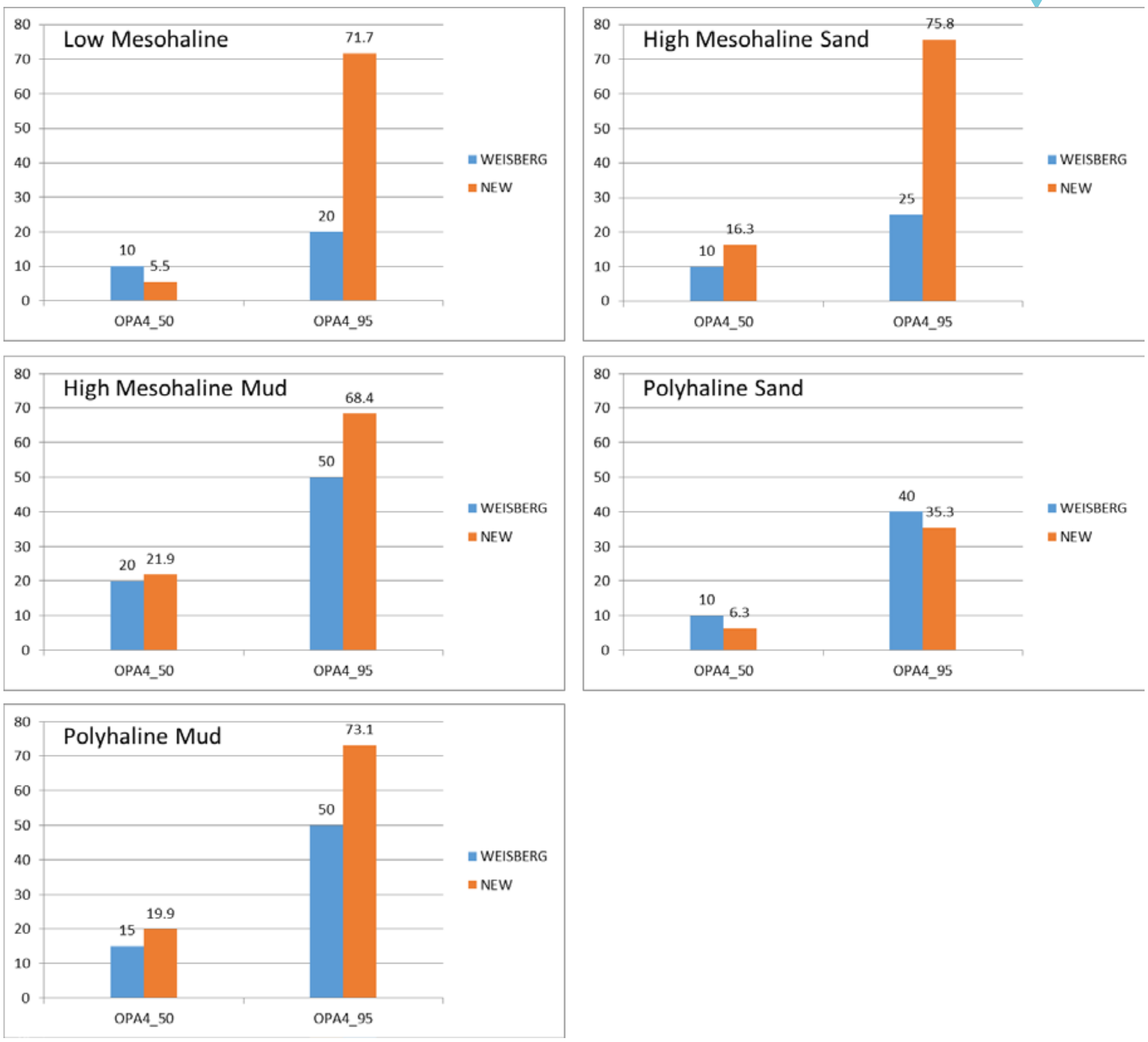

Figure 4. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of pollution indicative taxa (%).

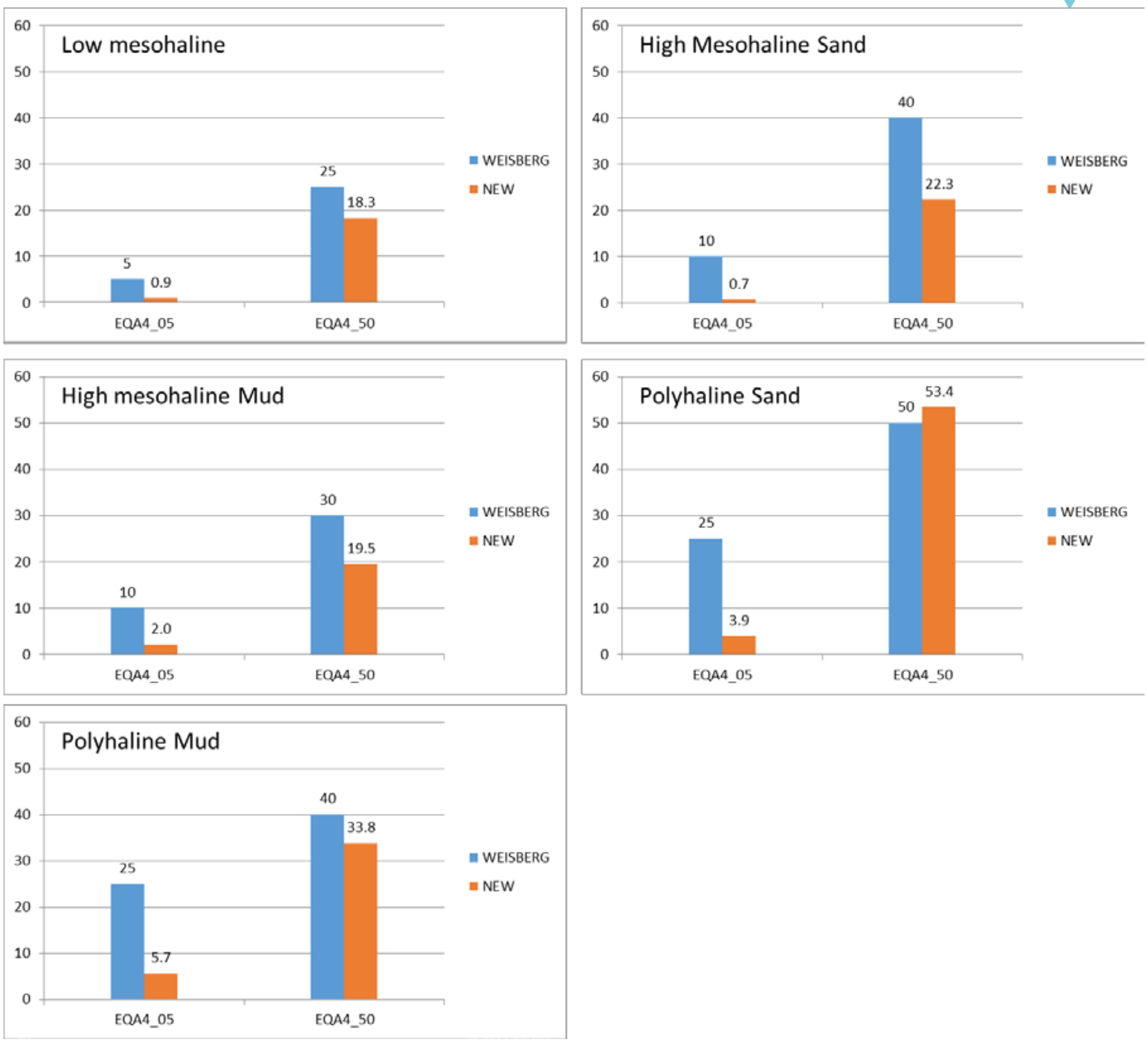

Figure 5. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of pollution sensitive taxa (%).

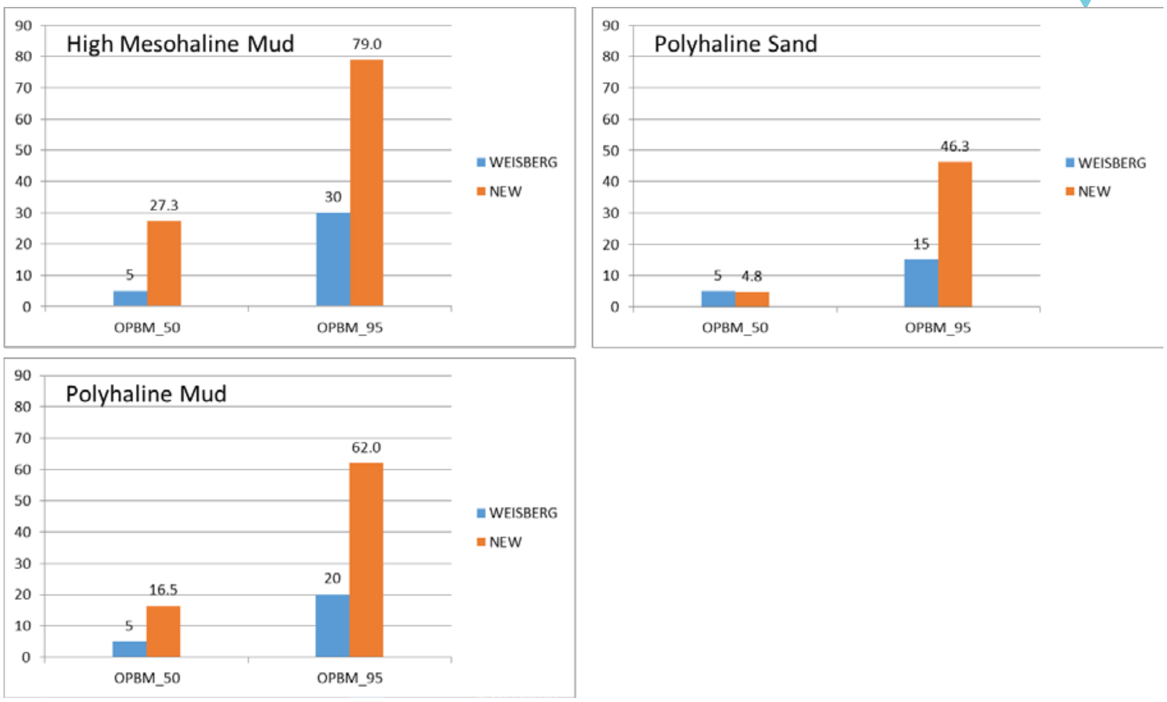

Figure 6. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for biomass of pollution indicative taxa (%).

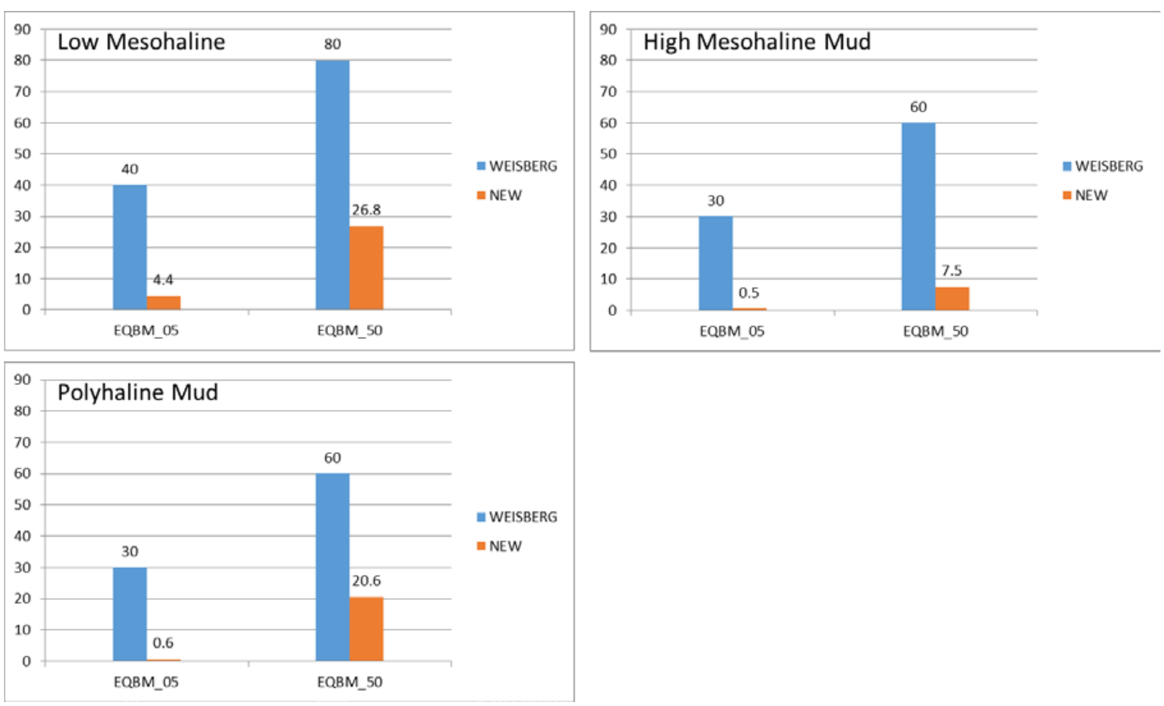

Figure 7. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for biomass of pollution sensitive taxa (%).

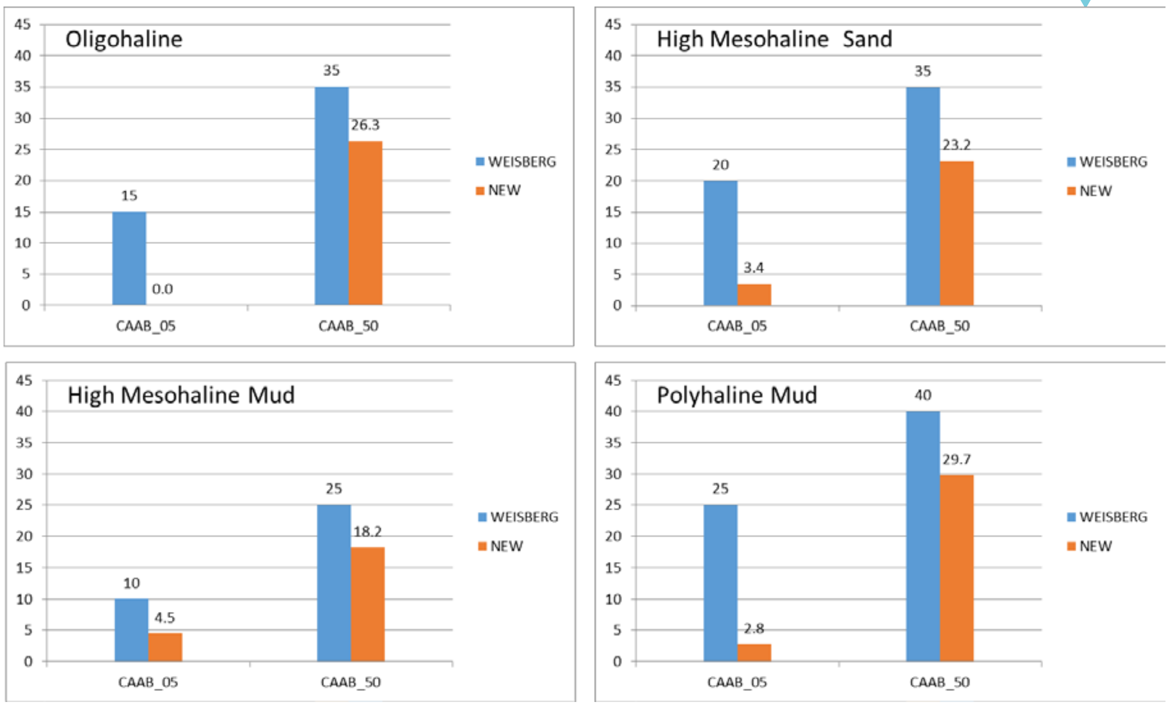

Figure 8. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of carnivore and omnivores (%)

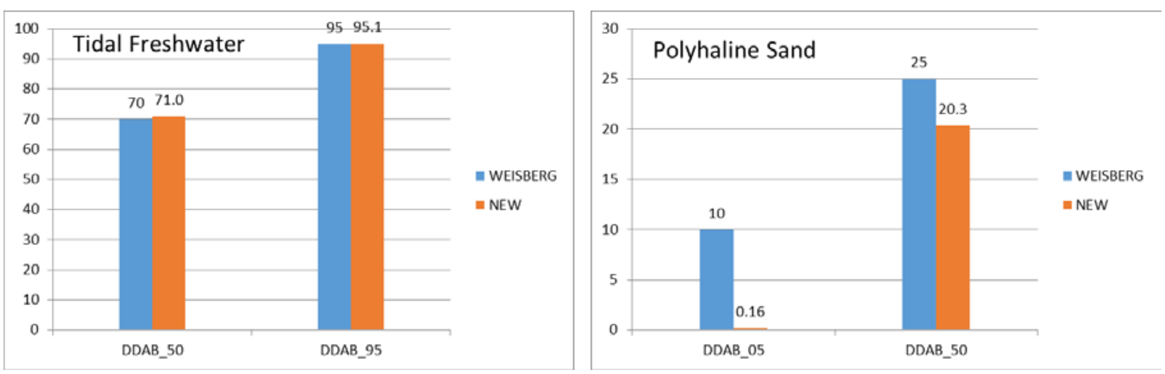

Figure 9. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of deep-deposit feeders (%).

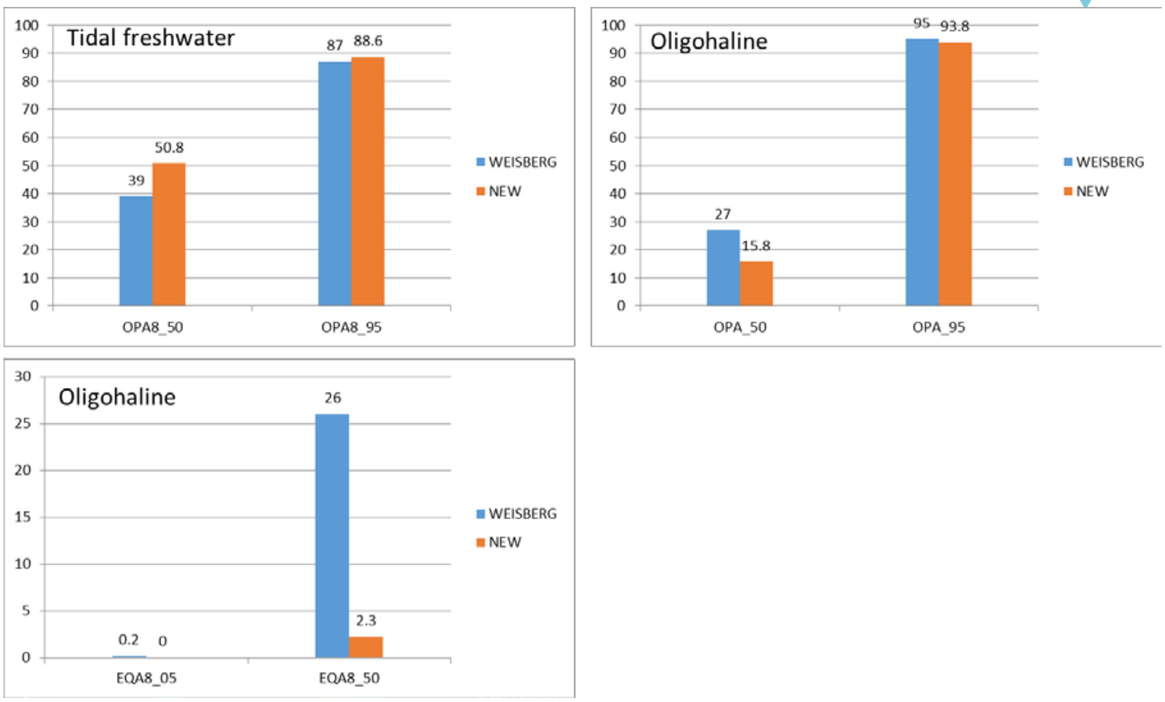

Figure 10. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for abundance of pollution indicative freshwater and oligohaline taxa (%, upper panel), and abundance of pollution sensitive oligohaline taxa (%, lower panel).

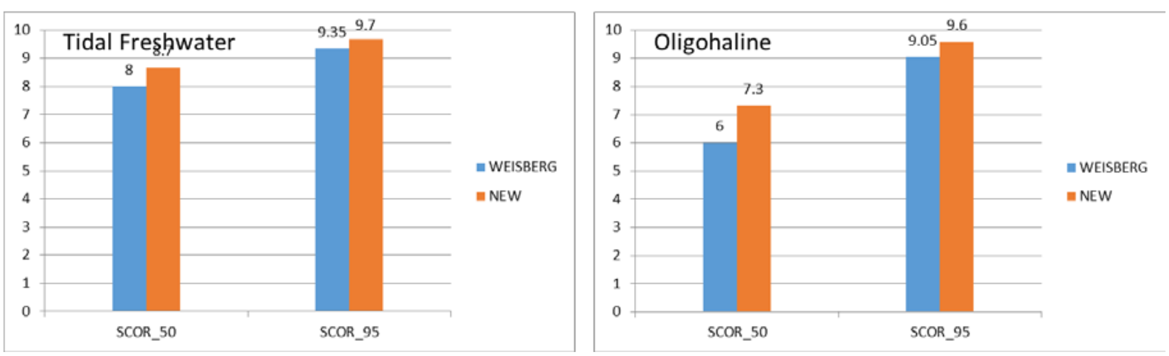

Figure 11. Comparison of thresholds between the original Reference dataset of Weisberg et al. (1997) and the new Reference dataset assembled for this project for Tolerance Score.

VALIDATION ASSESSMENTS
Original Thresholds

Validation assessment of the original B-IBI thresholds developed by Weisberg et al. (1997) and later updated by Alden et al. (2002) showed classification efficiencies ranging from a minimum of 45% correct classification in the Tidal Freshwater habitat type to a maximum of 81% correct classification in the Polyhaline Mud habitat (Table 5). Classification efficiencies for Low Mesohaline, High Mesohaline Sand, High Mesohaline Mud, and Polyhaline Mud habitat types were higher for Degraded sites than for Reference sites ranging from 55% to 92% (Table 5). Classification efficiencies were higher for Reference sites for Tidal Freshwater, Oligohaline, and Polyhaline Sand habitats in the 68-73% range (Table 5).

Table 5. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using thresholds defined in Weisberg et al. (1997) and Alden et al. (2002) and the entire calibration and validation datasets assembled for this project. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI is provided in **bold.**

			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Tidal Freshwater	Reference	55	40	72.7
	Degraded	161	58	36.0
	Total	216	98	45.4
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Oligohaline	Reference	24	17	70.8
	Degraded	111	70	63.1
	Total	135	87	64.4
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Low Mesohaline	Reference	92	51	55.4
	Degraded	214	156	72.9
	Total	306	207	67.6
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
High Mesohaline Sand	Reference	189	91	48.2
	Degraded	58	32	55.2
	Total	247	123	49.8
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
High Mesohaline Mud	Reference	106	30	28.3
	Degraded	309	241	78.0
	Total	415	271	65.3
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Polyhaline Sand	Reference	240	163	67.9
	Degraded	46	23	50.0
	Total	286	186	65.0
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Polyhaline Mud	Reference	47	18	38.3
	Degraded	179	164	91.6
	Total	226	182	80.5
	Overall	**1831**	**1154**	**63.0**

New Thresholds With and Without Modified Biomass Scoring

Validation of the B-IBI scored using new thresholds developed from old (data available to Weisberg et al.) and new probability-based data showed total classification efficiencies ranging from a minimum of 31% correct classification in the Oligohaline habitat type to a maximum of 68% correct classification in the Polyhaline Sand habitat (Table 6). Classification efficiencies for Reference sites were substantially higher than for Degraded sites (Table 6) ranging from 56% in the Oligohaline to 100% correct classification in Polyhaline Sand. Classification efficiencies for Degraded sites were less than 50% in all habitat types (Table 6). Modification of the procedure for scoring biomass using the same thresholds resulted in little and often no change in classification efficiency for all of the habitat types for both Reference and Degraded sites (Table 7).

Table 6. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using new thresholds and the validation dataset assembled for this project. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI approach is provided in **bold.**

Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
Tidal Freshwater	Reference	22	15	68.2
	Degraded	161	49	30.4
	Total	183	64	35.0
Oligohaline	Reference	9	5	55.6
	Degraded	111	32	28.8
	Total	120	37	30.8
Low Mesohaline	Reference	33	25	75.8
	Degraded	214	101	47.2
	Total	247	126	51.0
High Mesohaline Sand	Reference	65	53	81.5
	Degraded	58	18	31.0
	Total	123	71	57.7
High Mesohaline Mud	Reference	39	32	82.1
	Degraded	309	159	51.5
	Total	348	191	54.9
Polyhaline Sand	Reference	81	77	95.1
	Degraded	46	9	19.6
	Total	127	86	67.7
Polyhaline Mud	Reference	15	15	100
	Degraded	179	70	39.1
	Total	194	85	43.8
	Overall	**1342**	**660**	**49.2**

Table 7. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using new thresholds, the validation dataset assembled for this project, and a modified procedure for scoring biomass. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI approach is provided in **bold.**

Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
Tidal Freshwater	Reference	22	15	68.2
	Degraded	161	49	30.4
	Total	183	64	35
Oligohaline	Reference	9	5	55.6
	Degraded	111	32	28.8
	Total	120	37	30.8
Low Mesohaline	Reference	33	28	84.9
	Degraded	214	96	44.9
	Total	247	124	50.2
High Mesohaline Sand	Reference	65	56	86.2
	Degraded	58	18	31
	Total	123	74	60.2
High Mesohaline Mud	Reference	39	34	87.2
	Degraded	309	149	48.2
	Total	348	183	52.6
Polyhaline Sand	Reference	81	76	93.8
	Degraded	46	9	19.6
	Total	127	85	66.9
Polyhaline Mud	Reference	15	14	93.3
	Degraded	179	72	40.2
	Total	194	86	44.3
	Overall	**1342**	**653**	**48.7**

New Thresholds Based on Means With and Without Modified Biomass Scoring

Classification efficiencies obtained for the B-IBI based on thresholds developed using a calibration dataset of mean replicate values were, in general, similar to those obtained from thresholds developed using a calibration dataset of individual replicate values (presented above), although the overall classification efficiency improved slightly (Table 8). Total classification efficiencies by habitat type ranged from a minimum of 32% correct classification in the Oligohaline habitat type to a maximum of 71% correct classification in Polyhaline Sand habitat (Table 8). In general, classification efficiencies for Reference sites were substantially higher within habitat types than for Degraded sites (Table 8). Modification of the procedure for scoring biomass resulted in almost no changes in classification efficiencies with the exception of a slight improvement in the classification of Degraded sites within the Polyhaline Sand habitat (Table 9).

Table 8. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using new thresholds (developed from mean replicate values) and the validation dataset assembled for this project. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI approach is provided in **bold.**

Habitat	*a priori* Classification	Sample #	Correctly Classified	
			Number	Percentage
Tidal Freshwater	Reference	7	4	57.1
	Degraded	84	46	54.8
	Total	91	50	54.9
Habitat	*a priori* Classification	Sample #	Correctly Classified	
			Number	Percentage
Oligohaline	Reference	5	4	80
	Degraded	55	15	27.3
	Total	60	19	31.7
Habitat	*a priori* Classification	Sample #	Correctly Classified	
			Number	Percentage
Low Mesohaline	Reference	15	13	86.7
	Degraded	107	37	34.6
	Total	122	50	41
Habitat	*a priori* Classification	Sample #	Correctly Classified	
			Number	Percentage
High Mesohaline Sand	Reference	39	37	94.9
	Degraded	32	9	28.1
	Total	71	46	64.8
Habitat	*a priori* Classification	Sample #	Correctly Classified	
			Number	Percentage
High Mesohaline Mud	Reference	18	16	88.9
	Degraded	181	85	47

Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
	Total	199	101	50.8
Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
Polyhaline Sand	Reference	52	49	94.2
	Degraded	26	6	23.1
	Total	78	55	70.5
Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
Polyhaline Mud	Reference	11	11	100
	Degraded	109	40	36.7
	Total	120	51	42.5
	Overall	**741**	**372**	**50.2**

Table 9. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using new thresholds (developed from mean replicate values), the validation dataset assembled for this project, and a modified procedure for scoring biomass. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI approach is provided in **bold.**

Habitat	*a priori* Classification	Sample #	Correctly Classified Number	Correctly Classified Percentage
Tidal Freshwater	Reference	7	4	57.1
	Degraded	84	46	54.8
	Total	91	50	54.9
Oligohaline	Reference	5	4	80.
	Degraded	55	15	27.3
	Total	60	19	31.7
Low Mesohaline	Reference	15	14	93.3
	Degraded	107	35	32.7
	Total	122	49	40.2
High Mesohaline Sand	Reference	39	36	92.3
	Degraded	32	9	28.1
	Total	71	45	63.4
High Mesohaline Mud	Reference	18	16	88.9
	Degraded	181	84	46.4
	Total	199	100	50.3
Polyhaline Sand	Reference	52	49	94.2
	Degraded	26	6	23.1
	Total	78	55	70.5
Polyhaline Mud	Reference	11	11	100
	Degraded	109	45	41.3
	Total	120	56	46.7
	Overall	**741**	**374**	**50.5**

Table 10. Classification efficiencies within habitat type and across all habitat types for both Reference and Degraded sites based on B-IBI values scored using new thresholds (developed from mean replicate values of post-1997 samples), the validation dataset assembled for this project, and a modified procedure for scoring biomass. Provided are the total number of validation samples (Sample #) and the number and percentages of samples correctly classified within each habitat type and a priori impact classifications. Overall classification efficiency for this B-IBI approach is provided in **bold.**

			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Tidal Freshwater	Reference	7	7	100
	Degraded	50	18	36
	Total	57	25	43.9
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Oligohaline	Reference	4	4	100
	Degraded	27	10	37
	Total	31	14	45.2
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Low Mesohaline	Reference	10	9	90
	Degraded	56	7	12.5
	Total	66	16	24.2
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
High Mesohaline Sand	Reference	30	26	86.7
	Degraded	20	10	50
	Total	50	36	72
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
High Mesohaline Mud	Reference	20	17	85
	Degraded	120	54	45
	Total	140	71	50.7
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Polyhaline Sand	Reference	41	39	95.1
	Degraded	18	4	22.2
	Total	59	43	72.9
			Correctly Classified	
Habitat	*a priori* Classification	Sample #	Number	Percentage
Polyhaline Mud	Reference	12	12	100
	Degraded	74	12	16.2
	Total	86	24	27.9
	Overall	**489**	**229**	**46.8**

Thresholds based on data collected after 1997

Classification efficiencies obtained for the B-IBI based on thresholds developed using a calibration dataset of mean replicate values and only post-1997 data (i.e., EMAP and MAIA datasets excluded) were slightly lower overall to those obtained using other methods (Table 10). Total classification efficiencies by habitat type ranged from a minimum of 24% correct classification in the Low Mesohaline habitat to a maximum of 73% correct classification in the Polyhaline Sand habitat (Table 10). In general, classification efficiencies for Reference sites were substantially higher within habitat types than for Degraded sites.

Summary

Overall, modifications to the original thresholds of Weisberg et al. (1997) and Alden et al. (2002) based either on changes to the datasets used or the procedure for scoring biomass resulted in decreases in overall classification efficiencies (Figure 12). A closer examination of classification efficiencies within habitat types and a priori impact classification groups indicates that the B-IBI based on new thresholds (Iteration 1), in general, had higher classification efficiencies for Reference sites while the B-IBI based on original thresholds (the baseline) had higher classification efficiencies for Degraded sites for most habitat types (Figure 13). Similar results were obtained for other iterations, including modifications to the existing biomass scoring procedure (see Tables 7 to 10). These results indicate that additional datasets or modifications to existing procedures did not improve the classification efficiency of the B-IBI in any of the habitats to a degree that would warrant adoption of any of the iterations here examined.

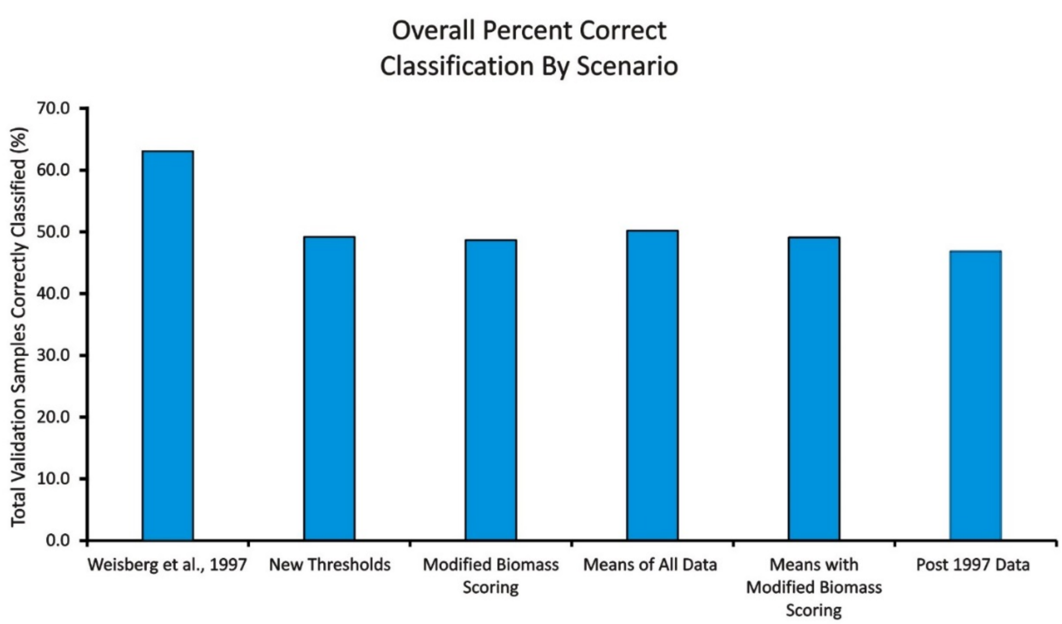

Figure 12. Overall classifications efficiencies for data assembled in this project using the original Weisberg et al. (1997) and Alden et al. (2002) thresholds (the baseline), and new thresholds with or without further modifications to datasets or biomass scoring procedure

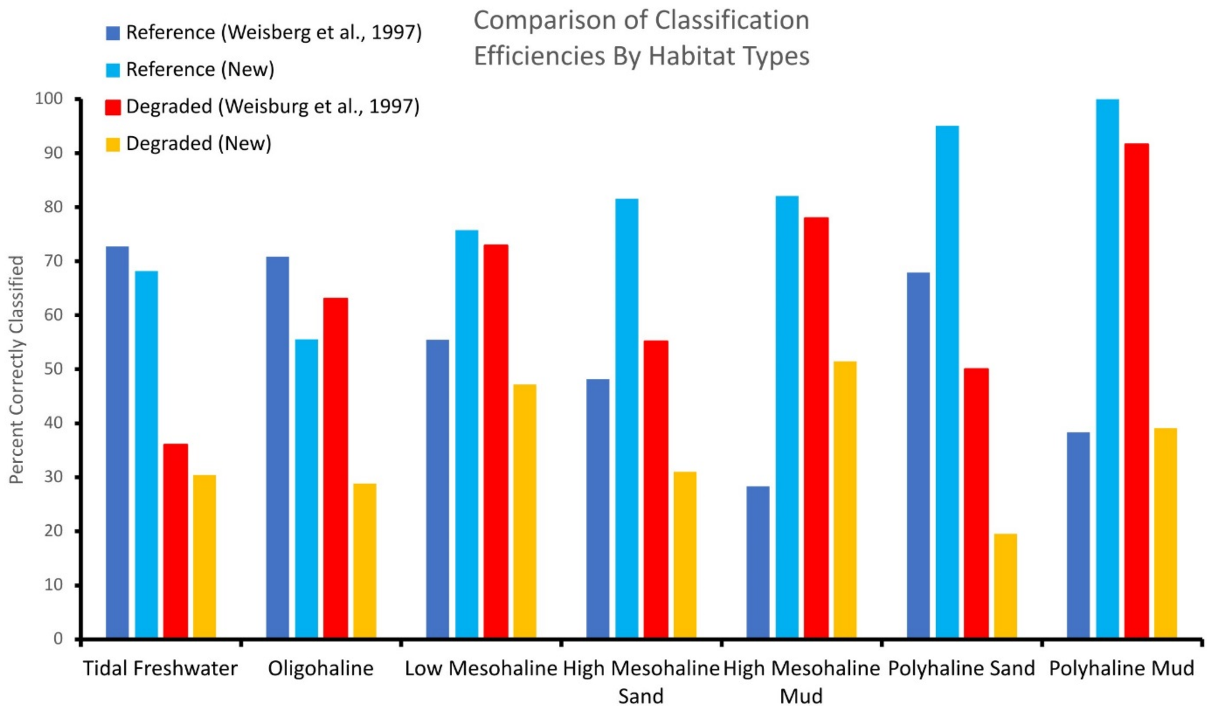

Figure 13. Classification efficiencies for validation dataset for Reference and Degraded sites by habitat type obtained using the original (Weisberg et al., 1997) thresholds and new thresholds for the B-IBI

WATER DEPTH ANALYSIS

The validation assessments indicated that additional data did not improve the classification efficiency of the B-IBI. Further, the new calibration data included many more depauperate samples than the data of the initial calibration effort. Also, the new data did not improve the challenges in the low salinity habitats. When the calibration data were segregated by depth, it was noted shallow versus deep differences among the values of a metric. For data after 1996 (i.e., excluding the EMAP samples), the lowest values in the calibration dataset below the lower 5th percentile threshold (or the highest values above the upper 95th percentile threshold) were on average in shallow water for most metrics (Table 11). Some of the differences were statistically significant. The Polyhaline Sand and Polyhaline Mud habitats have a water depth boundary of about 3-4 m (Table 12). This corresponds to Reilly's 4 m boundary, an area of "maximum interaction between human activities and biological resources" (Reilly 1996). Thus, water depth may be a surrogate for nearshore anthropogenic effects.

Table 11. Average water depth (m) of calibration samples for metrics below the original Weisberg et al. (1997) 5th percentile threshold, or above the 95th percentile threshold. Data after 1996. Numbers in bold and underlined are significantly different by t-test at the 0.05 probability level. Shaded cells indicate depths that are, on average, lower for "bad" values of a metric (values below the 5th percentile threshold or above the 95th percentile threshold) than for "good" values. Blanks denote metrics that are not attributes of the B-IBI in that habitat. * >95th percentile threshold.

Habitat	Shannon (H')		Abundance		Biomass		Pollution Indicative Abundance		Pollution Sensitive Abundance		Pollution Indicative Biomass	
	Low	High	Low/High	Medium	Low	High	High*	Low	Low	High	High*	Low
Polyhaline Sand	4.0	4.8	**3.2**	**5.1**	**3.7**	**5.5**	.	.	4.5	4.5	3.4	5.1
Polyhaline Mud	**3.1**	**7.1**	3.6	6.1	4.4	6.0	.	.	.	.	4.5	7.1
High Mesohaline Mud	3.8	2.7	3.3	2.6	2.4	3.4	.	.	.	.	2.8	2.9
High Mesohaline Sand	2.4	2.7	2.2	2.8	2.8	2.4	2.8	2.4	**1.9**	**2.9**	.	.
Low Mesohaline	1.9	2.1	3.2	1.9	1.8	2.5	2.1	2.1	.	.	.	.
Oligohaline	.	.	4.1	2.3	.	.	3.2	2.5	2.0	3.2	.	.
Tidal Freshwater	.	.	3.0	3.0	.	.	n/a	3.0	.	.	.	.

Habitat	Pollution Sensitive Biomass		Carnivore and Omnivore Abundance		Deep Deposit Feeder Abundance		Tolerance Score		Tanypodinae/ Chironomidae Abundance Ratio	
	Low	High	Low	High	Low	High	High*	Low	High*	Low
Polyhaline Sand	.	.	.	.	4.8	4.3	.	.	.	.
Polyhaline Mud	4.0	7.3	**3.2**	**8.7**	.	.	.	.	.	.
High Mesohaline Mud	2.7	3.5	2.1	3.1	.	.	.	.	.	.
High Mesohaline Sand	.	.	2.1	3.0	.	.	.	.	.	.
Low Mesohaline	1.9	2.5	.	.	.	.	.	.	.	.
Oligohaline	.	.	2.0	2.9	.	.	2.4	2.7	1.5	2.8
Tidal Freshwater	.	.	.	.	3.0	n/a*	5.5	2.8	.	.

Table 12. Comparisons of B-IBI component metrics between shallow (<=4 m) and deep (>4 m) samples in the Polyhaline Sand Reference habitat. Provided are descriptive statistics, results of two-tailed Student's t-tests and equality of variance tests for each metric. If test for equality of variance is significant, then t-test provided is for unequal variances.

Abundance (#/m²)											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	7,876	21359.8	2962.1	52.1	-1.64	0.11	51	42	109.4	<0.001
Deep	43	2,997	2042	311.4							
Biomass (g AFDW/m²)											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	3.19	16.01	2.22	52.4	-0.68	0.5	51	42	86.66	<0.001
Deep	43	1.67	1.72	0.26							
Shannon Index (H')											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	2.58	0.9	0.12	93	1.85	0.07	51	42	1.03	0.93
Deep	43	2.92	0.89	0.14							
Pollution Sensitive Abundance (%)											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	48.9	27.73	3.85	93	-1.29	0.2	51	42	1.24	0.47
Deep	43	41.9	24.89	3.8							
Pollution Indicative Biomass (%)											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	19	18.22	2.53	90.7	-2.97	**<0.001**	51	42	2.03	0.02
Deep	43	9.48	12.78	1.95							
Deep Deposit Feeder Abundance (%)											
	Descriptive Statistics				t Test				Equality of Variance Test		
Class	N	Mean	Std. Dev.	Std. Error	DF	t Value	P > t	Num DF	Den DF	F	P>F
Shallow	52	23.8	20.69	2.87	87.9	-1.92	0.06	51	42	2.44	<0.001
Deep	43	17.1	13.25	2.02							

POLLUTION TOLERANCE

The pollution tolerance of benthic species typically is categorized based on their life-history characteristics (Dauer 1993). However, in some cases life-history characteristics are inconsistent with pollution tolerance (Seitz and Schaffner 1995). Capitellid polychaetes, for example, have been identified as opportunistic (high reproductive output, rapid growth), but in Chesapeake Bay a key species, *Mediomastus ambiseta*, was found in higher numbers in reference sites than in degraded sites (Weisberg et al. 1997). This species is currently listed as pollution sensitive in the B-IBI. One concern with this species listed as pollution sensitive is its dominance throughout the Elizabeth River. Of special concern is its dominance in the Southern Branch and some smaller creeks of the Southern Branch, all considered highly anthropogenically stressed. In addition this species has increased greatly in dominance over the years. Based on these concerns, *Mediomastus ambiseta* classification as pollution sensitive in the B-IBI was reconsidered during the present effort by testing for differences in abundance among sites in the more recent data.

Results of t-test comparing the abundance of *M. ambiseta* between Reference and Degraded sites indicated no significant differences in means for any of the habitat types (Table 13). However, results were more complicated when examined using nonparametric procedures and distribution tests. Wilcoxon two-sample tests for both High Mesohaline Mud, High Mesohaline Sand, and Polyhaline Mud habitats indicated median abundances of *M. ambiseta* significantly higher in Reference than in Degraded sites. Additionally there were significantly differences in the distribution of this species between Reference and Degraded sites for these habitat types (Table 13). In the Polyhaline Sand, no significant differences between medians or distributions were observed.

These results indicate that *M. ambiseta* could not be consistently characterized as being strictly representative of either Reference or Degraded sites. This species has been referred to as opportunistic and pollution indicative based both on ecological surveys (Grassle and Grassle, 1974; Boesch, 1977; Billheimer et al., 1997) and experimental results (Shaffner, 1990). Given the evidence from the literature in combination with the results of this study, it is likely that retaining *M. ambiseta* as either pollution sensitive or pollution indicative for the purposes of the B-IBI calculation is likely to result in sample misclassifications, and is therefore unwarranted.

Table 13. Summary of two sample comparisons of mean and median abundance of *Mediomastus ambiseta* between Degraded and Reference sites for High Mesohaline Sand, High Mesohaline Mud, Polyhaline Sand and Polyhaline Mud habitat types. Provided for each habitat type are descriptive statistics, t-test results, equality of variance tests (all indicating significantly different variances), Wilcoxon two-sample, and Kolmogorov-Smirnov comparisons of distributions.

High Mesohaline Sand	Descriptive Statistics				t-Test (unequal Variances)			Equality of Variance Test		Wilcoxon Two Sample test			Kolmogorov-Smirnov Test	
Impact Classification	N	Mean	Std. Dev.	Std. Error	D.F.	t Value	P > t	F	P > F	W Value	Z	P>Z	KS_a	$P>KS_a$
Degraded	56	27.7	184.40	24.64	57.78	0.47	0.641	12.99	<0.001	5506	-2.43	0.008	1.49	0.023
Reference	172	16.0	51.16	3.90										
High Mesohaline Mud	**Descriptive Statistics**				**t-Test (unequal Variances)**			**Equality of Variance Test**		**Wilcoxon Two Sample T-test**			**Kolmogorov-Smirnov Test**	
Impact Classification	N	Mean	Std. Dev.	Std. Error	D.F.	t Value	P > t	F	P > F	W Value	Z	P>Z	KS_a	$P>KS_a$
Degraded	264	7.3	49.69	3.06	211.85	-1.21	0.224	1.47	0.027	22307	6.52	<0.001	2.72	<0.001
Reference	99	13.5	40.98	4.12										
Polyhaline Sand	**Descriptive Statistics**				**t-Test (unequal Variances)**			**Equality of Variance Test**		**Wilcoxon Two Sample T-test**			**Kolmogorov-Smirnov Test**	
Impact Classification	N	Mean	Std. Dev.	Std. Error	D.F.	t Value	P > t	F	P > F	W Value	Z	P>Z	KS_a	$P>KS_a$
Degraded	41	28.3	36.40	5.69	78.38	-0.09	0.933	1.93	0.016	4602	-0.13	0.4463	0.8	0.540
Reference	185	28.9	50.55	3.72										
Polyhaline Mud	**Descriptive Statistics**				**t-Test (unequal Variances)**			**Equality of Variance Test**		**Wilcoxon Two Sample T-test**			**Kolmogorov-Smirnov Test**	
Impact Classification	N	Mean	Std. Dev.	Std. Error	D.F.	t Value	P > t	F	P > F	W Value	Z	P>Z	KS_a	$P>KS_a$
Degraded	152	26.4	63.26	5.13	78.62	-1.58	0.119	1.74	0.045	5338	4.78	<0.001	2.35	<0.001
Reference	40	40.8	47.97	7.58										

CONCLUSIONS

1. Additional data did not improve the classification efficiency of the B-IBI in any of the habitats.
2. Data did not improve the challenges in the lower salinity habitats. This is a global issue with no obvious solution.
3. Samples meeting the reference criteria included enough samples with low diversity, abundance, biomass, and numbers of pollution indicate and sensitive taxa to bias the data toward too many false positives of undegraded condition.
4. There are at least two hypotheses relative to the lowered thresholds and unacceptable correct classification efficiencies compared to the baseline:

a. Anthropogenic stress criteria not accounted for by this study might better classify samples into Reference and Degraded categories. However, the same criteria that were used in the initial calibration effort were used in this study. Water depth as a surrogate for nearshore anthropogenic effect is one possible new criterion.

b. There is a subtle deterioration of water quality in the Bay that has resulted in false positives in our calibration dataset.

5. A reasonable next step is a best professional judgement approach to determining biological criteria, similar to that of Weisberg et al. (2008).

LITERATURE CITED

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical verification of the Chesapeake Bay benthic index of biotic integrity. Environmetrics 13:473-498.

Billheimer, D., D.T. Cardoso, E. Freeman, P. Guttorp, H. Ko, and M. Silkey. 1997. Natural variability of benthic species composition in the Delaware Bay. Environmental and Ecological Statistics. 4:95-115.

Boesch, D.F. 1977. A new look at the zonation of benthos along the estuarine gradient. Pp. 245-266 *In* B.C. Coull (ed.), Ecology of Marine Benthos, University South Carolina Press, Columbia, SC.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. Marine Pollution Bulletin 26:249-257.

Dauer, D.M. and M.F. Lane. 2005. Side-by-side comparison of Young grab and composite petite ponar grab samples for the calculation of the Benthic Index of Biological Index (B-IBI). Report to the Virginia Department of Environmental Quality by Old Dominion University, Norfolk VA. 46 pp.

Grassle, J. F. and Grassle, J. P. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. Journal of Marine Research 32:253-284.

Hyland, J.F., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers and R.F. Van Dolah. 2003. Incidence of stress in benthic communities along the U.S. Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environmental Monitoring and Assessment 81:149-161.

Llansó, R.J., L.C. Scott, D.M. Dauer, J.L. Hyland, and D.E. Russell. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the United States. I. Classification of assemblages and habitat definition. Estuaries 25:1219-1230.

Llansó R.J., J.H. Vøstad, D.M. Dauer and J.R. Dew. 2009. Assessing benthic community condition in Chesapeake Bay: does the use of different benthic indices matter? Environmental Monitoring and Assessment 150:119-127.

Long, E.R., D.D. MacDonald, S.l. Smith, and F.D. Calder. 1995. Incidence of adverse environmental effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19:81-97.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1994. Chesapeake Bay Benthic Community Restoration Goals. Report prepared for the U.S. Environmental Protection Agency Chesapeake Bay Program Office, the Governor's Council on Chesapeake Bay Research Fund, and the Maryland Department of Natural Resources by Versar, Inc., Columbia, Maryland.

Reilly Jr., F.J., R.J. Spagnolo, and E. Ambrogio. 1996. Marine and estuarine shallow water science and management. Estuaries 19:166–168.

Schaffner L.C. 1990. Small-scale organism distributions and patterns of species diversity: evidence for positive interactions in an estuarine benthic community. Marine Ecology Progress Series 61:107-117.

Seitz, R.D. and L.C. Schaffner. 1995. Polulation ecology and secondary production of the polychaete *Loimia medusa* (Terebellidae). Marine Biology 121:701-711.

Van Dolah, R.F., J.L. Hyland, A.F. Holland, J.S. Rosen, and T. R. Snoots. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the Southeastern USA. Marine Environmental Research 48:269-283.

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

Weisberg, S.B., B. Thompson, J.A. Ranasinghe, D.E. Montagne, D.B. Cadien, D.M. Dauer, D. Diener, J. Oliver, D.J. Reish, R.G. Velarde, and J.Q. Word. 2008. The level of agreement among experts applying best professional judgment to assess the condition of benthic infaunal communities. Ecological Indicators 8:389-394.