Review and Potential Refinement of the Definition for "Instantaneous Minimum" Dissolved Oxygen Criteria Supporting Chesapeake Bay Water Quality Standards Assessment: A Chesapeake Bay Program Workshop

A joint meeting supported by the CBP Science, Technical Assessment and Reporting Team and its Tidal Monitoring and Assessment and Criteria Assessment Protocol Workgroups

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Background

Under EPA guidance, minimum criteria are acute criteria to be achieved at all times (U.S. EPA 1986). Chronic water quality criteria are always expressed as average concentrations over at least several days such as EPA's chronic water quality criteria for toxics in freshwater environments expressed as 4-day averages (U.S. EPA 2004). By comparison, for acute criteria, EPA has recommended an averaging period of 1 hour. That is, to protect against acute effects, the 1-hour average exposure should not exceed (or, in the case of dissolved oxygen, go below) the critical concentration (U.S. EPA Standards Handbook).

Specific to Chesapeake Bay, in 1992, progress toward developing dissolved oxygen goals for restoration of living resource habitats led to recommended target concentrations that included minimums (e.g. dissolved oxygen $\geq$ 1mg O_2/L, all times and all locations; dissolved oxygen $\geq$ 5 mg O_2/L, all times, throughout above-pycnocline waters in spawning reaches, spawning rivers and nursery areas). National DO criteria further included a multifaceted, multidimensional exposure concept that has carried through into the definition of water quality standards. The definition of a water quality standard as explained in Chapter 3 of the U.S. EPA *Water Quality Standards Handbook, 2nd Edition* (U.S. EPA 1994) and in U.S. EPA (2003) indicates water quality criteria definitions and assessments are not only comprised of a criterion magnitude but include duration and frequency of the condition.

In April 2003, the EPA published the guidance document *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal tributaries* (U.S. EPA 2003) http://www.epa.gov/region3/chesapeake/baycriteria/Criteria_Final.pdf with criteria and assessment procedures addressing the multiple dimensions needed for Bay water quality standards. In the Chesapeake Bay criteria context, *magnitude* is defined by each criterion threshold. *Duration* of a condition is addressed by the season for which the criterion applies and by the assessment period, i.e. "the most recent three consecutive years for which relevant monitoring data are available" (U.S. EPA 2003). *Frequency* is addressed by comparisons of the generated cumulative frequency distribution (CFD) with the applicable criterion reference curve in the impairment assessment (U.S. EPA 2003). Instantaneous minimum dissolved oxygen criteria were developed here as elements of the suite of criteria applied to Chesapeake Bay tidal

waters to support Clean Water Act section 303d water quality standards assessments (U.S. EPA 2003a, Batiuk et. al. 2009, Tango and Batiuk 2013). All of the refined Chesapeake Bay tidal water designated uses (i.e. Open Water, Deep Water, Deep Channel, Migratory and Spawning, and Shallow Water Bay Grass use) include an instantaneous minimum dissolved oxygen criterion (Table 1). Chesapeake Bay dissolved oxygen criteria and their assessment protocols accounting for magnitude, duration and frequency of conditions have been adopted into the water quality standards of the tidal water jurisdictions (i.e. Maryland, Delaware, Virginia and Washington, DC).

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

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

Assessment of Instantaneous Minimum Criteria

The tidal water Chesapeake Bay water quality standards attainment assessments are conducted using cumulative frequency distributions (CFDs) to evaluate spatial and temporal water quality criteria exceedances (see Chapter vi in U.S. EPA 2003). CFDs are developed from Bay water quality monitoring data and compared against a reference curve to assess attainment status of a Chesapeake Bay management segment. Reference curves are used in the attainment assessment providing for an allowable exceedance of a criterion.

U.S. EPA (2004) guidance on a 10% rule of allowable exceedance was intended to provide a simple "rule of thumb" in evaluating data sets of limited size for assessment purposes and is intended to account for measurement error and the potential that small data sets may not be fully representative of receiving water conditions. Coincidentally, the EPA's criteria derivation guidelines and technical support documents do not state that the purpose of the criteria is to prevent any losses; rather, the purpose of the criteria is to prevent "unacceptable losses". Allowable exceedances as applied within the present framework of Chesapeake Bay dissolved oxygen standards impairment assessments accepts spatial and temporal exceedances of the criterion by incorporating into the analysis either a 10% curve or a biological reference otherwise referred to as a bio-reference curve (U.S. EPA 2003a).

Assessment of instantaneous minimum criteria in Chesapeake Bay is presently only conducted for the summer season deep channel designated use. A biological reference curve was initially used in assessing impairment status of the deep channel habitat as recommended in U.S. EPA 2007 (p43). (Also see *History of EPA Guidance on the deep channel reference curve* in Appendix D, U.S. EPA 2010). The 2007 recommendation for application of a biologically-based reference curve to assess deep channel dissolved oxygen criterion attainment was supported by a small number of deep-channel Chesapeake Bay Program management segment-periods (i.e. management segments over a period of years assessed for healthy or degraded benthic community status) where the benthic communities were categorized as "healthy" and, therefore, appropriate to use as a biological reference (U.S. EPA 2010). In 2010, U.S. EPA went on to publish a revised methodology on developing biological reference curves and an updated classification for delineating "healthy" and "degraded" benthic communities in the Bay. Using the method revisions and updates in an attempt to create a new deep channel biological reference curve, however, now showed no Chesapeake Bay management segment-periods with deep channel habitats having healthy benthic communities. In the absence of a suitable reference community, a biological reference curve could not be constructed. Under these circumstances, a default reference curve such as the normal distribution curve representing approximately 10% exceedance is appropriate in this case to account for anticipated natural exceedances (U.S. EPA 2003, p173.). Further detailed background on incorporating allowable exceedance into instantaneous minimum criteria assessments is provided here from U.S. EPA (2010) (See http://www.chesapeakebay.net/content/publications/cbp_51366.pdf):

Rationale for Acceptable Exceedances of the Deep Channel Instantaneous Minimum Dissolved Oxygen Criterion

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

> *"The recommended criteria attainment assessment approach is designed to protect the living resources as defined by the designated uses. The criteria levels themselves were largely base on scientific studies performed in laboratory settings or under controlled field conditions. The criteria establish the level of a given habitat condition that living resources need for survival. They do not account for many other environmental factors that could affect*

survival. Reference curves were developed to provide a scientific-based, direct measure of the 'allowable' criteria exceedances. These exceedances are defined to be those that last a short enough time to have no adverse affects on the designated use. It is assumed that the designated uses can be attained even with some limited level of criteria exceedances and thus, the reference curves define those criteria exceedances deemed to be allowable—chronic in time but over small areas, or infrequent occurrences over large areas. Exceedances that occur over large areas of space and time would be expected to have significant detrimental effects on biological communities, which would imply nonattainment of designated uses."

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

"Unlike chemical contaminants or other more conventional pollutants, there we no clear, no well established guidelines for deriving criteria for DO, particularly in estuarine settings inhabited by freshwater and marine species. The goal in setting Chesapeake DO criteria was to use the best science possible to define conditions that would improve or sustain the suitability of Chesapeake Bay habitats for finfish and invertebrates, with the states ultimately factoring in consideration of attainability in adopting the criteria as water quality standards. Thus, we developed criteria that would greatly increase the spatial and temporal extent of Bay waters in which oxygen concentrations were not major limitations to growth and survival of organisms dependent on particular Bay habitats. We did not, however, derive criteria that would require oxygen concentrations high enough at all times and in all locations such that no organism would be negatively affected in any location in the Bay. The states and U.S. Environmental Protection Agency (EPA) determined that such conditions would not be achievable either economically nor technologically (U.S. EPA, 2003d) and may not, in fact, reflect pre-historical conditions of Chesapeake Bay, which showed that low oxygen conditions, although not nearly as severe as today, may have been a historical feature in the deep channel of the bay (Cooper and Brush,1991; Karlsen et al., 2000; Adelson et al., 2001; Zimmerman and Canuel, 2002; Bratton et al., 2003; Colman and Bratton, 2003; Cronin and Vann, 2003; Zheng et al., 2003)."

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

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

EPA, therefore, recommended revision of the 2007 decision in 2010 to assess the summer season (June 1-September 30) deep channel instantaneous minimum criterion using the CFD approach with a 10% default reference curve (U.S. EPA 2010).

Alternative Criteria Attainment Assessment Options Proposed for Evaluating Short Duration Dissolved Oxygen Criteria Attainment

States adopted the full set of dissolved oxygen criteria that included instantaneous minimum criteria to protect the refined tidal water designated uses (see Table 1). U.S. EPA (2003) also recognized that there were limitations in direct monitoring at the temporal scales required for assessing short duration criteria (e.g. 7-day mean, 1-day mean, instantaneous minimum). Methods such as logistic regression and spectral analysis were suggested as potential approaches to be used for assessing short duration criteria (U.S. EPA 2003). States were provided an option to waive attainment assessment for short duration criteria until monitoring at the required temporal scales was implemented or statistical methods were available for estimating probable attainment of water quality standards (U.S. EPA 2003).

Implementation of New Monitoring Technologies in Chesapeake Bay Expanded the Data Evaluation Options Supporting Short Duration Dissolved Oxygen Criteria Attainment Methods Assessments.

The Chesapeake Bay Program's Umbrella Criteria Assessment Team (2010-2012) used the best available monitoring information to pursue alternative methods to the CFD for evaluating water quality standards attainment. Quality assured, quality controlled water quality data sets were targeted by the Umbrella Criteria Assessment Team to conduct their method evaluations (Table 2). 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 of criteria protections, the temporally dense, high frequency monitoring data sets were largely limited to U.S. EPA EMAP short-term buoy deployments (Table 2). At that time, season-long continuous dissolved oxygen monitoring data sets from tidal waters of Chesapeake Bay were not widely available. The focus on high frequency dissolved oxygen data collection was on the threshold of being incorporated into the new, shallow-water focused network of stations in an expanded Bay monitoring framework for the Chesapeake Bay Program. In 2004, the Chesapeake Bay Program formalized this monitoring network expansion in the tidal waters of the Bay 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 provided near-realtime data collection capabilities and produced water quality time series with temporally dense dissolved oxygen measurements at fixed depth, in vertical profile or pulled behind a boat to get multiple depths over space with high resolution, underway monitoring efforts.

Table 2. Data sources serving the Umbrella Criterion Assumption analyses.

Program Description	Data Collection and Availability	Sampling Locations and Habitats
CBP long-term water quality monitoring program: Low temporal frequency and spatial spatial resolution, good vertical profile resolution of the data collection.	1985-present. Biweekly to monthly sampling. Water column profiles taken with grab samples and sensors. Web accessible data: *CBP CIMS* accessible.	Fixed site, mid-channel, approximately 178 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.

Basis for the Umbrella Criterion Approach to Measuring Probability of Water Quality Standards Attainment

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

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

The Umbrella Effect for Criteria Assessment is Demonstrated.

The Umbrella Criteria Assessment Team pursued analyses of mutual protectiveness of dissolved oxygen criteria. An Umbrella Effect was demonstrated for the 30-day mean criterion and shorter-duration criteria in Chesapeake Bay. To apply this Umbrella Criterion Approach to water standards attainment assessments, you need to account for:

- *the sampling effort used in estimating the Umbrella Criterion (30-day mean) value must be accounted for, and*
- *an additional threshold must be met in order to fully express the level of protection provided for an unmeasured criterion as affected by the sample size*.
    - *Data variability affects the threshold*

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

Table 3. Summary of violation rates over levels of sensor depth to illustrate time series violations associated with a gradient of open water 30-day means in dissolved oxygen. (From Perry 2012a)

Monthly mean DO[1]	5.01	5.67	6.34	7.01
7-day criterion failure rate	17.7%	5.5%	2.1%	2%
Instantaneous minimum >10%	44.9%	34.3%	25.4%	16.6%

1. Columns 1-4 results were derived from high frequency sensor data at depths of 6,5,4,3 m respectively.

By comparison, in the practice of conducting Chesapeake Bay dissolved oxygen criteria attainment assessments, the 30-day mean dissolved oxygen concentration is estimated from as few as one to two point observations per month under the existing Chesapeake Bay long-term, fixed station water quality monitoring program. The uncertainty of estimating the monthly mean dissolved oxygen concentration using so few observations is much greater than the uncertainty of a monthly mean from near continuous sensor data. The impact of small sample size is to weaken the Umbrella Effect (Table 4).

Table 4. Estimates of risk of violating the 7-day criterion given the monthly mean estimate (column 1) and four levels of sampling variation (column 3). (Modified from Perry 2012b)

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

1 standard deviation of true weekly mean from true monthly mean
2 standard deviation base on pooling 20 resampling estimates
3 standard deviation based on the minimums of 20 resampling estimates
4 standard deviation based on the maximums of 20 resampling estimates

Considerations that are Being Given to Minimum DO Criteria Assessments Outside the Chesapeake Bay.

There is a lot of interest presently in assessing minimum DO standards throughout the United States. As mentioned previously, under EPA guidance, minimum criteria are acute criteria to be achieved at all times (U.S. EPA 1986) and are recommended to have a 1-hour averaging period. Regarding the choice of short duration dissolved oxygen criteria, some states, tribes and provinces have adopted 1-day minimum concentrations described as instantaneous minimums as their freshwater water quality standards; such a criterion may be coupled in the standards with needing to simultaneously meet other mean minimum criteria (Table 5).

Table 5. Pacific Northwest state, provincial and tribal freshwater criteria for the protection of salmon spawning. (Extracted from p11, https://fortress.wa.gov/ecy/publications/publications/0903039.pdf).

Agency/Institution	Water Column Measures		
	1 Day Minimum[1]	7-Day Mean Minimum[2]	30-Day Mean Minimum
Oregon	9.0 mg/L[3]	11.0 mg/L	
Idaho	6.0 mg/L[4]		
Alaska	7.0 mg/L		
Washington	9.5 mg/L		
British Columbia	9.0 mg/L		11.0 mg/L
Makah Tribe	9.5 mg/L	11.0 mg/L	
Port Gamble S'Klallam Tribe	9.0 mg/L	11.0 mg/L	
Confederated Tribes of the Umatilla Indian Reservation	9.0 mg/L	11.0 mg/L	
Lummi Nation	9.0 (11.0) mg/L		
Confederated Tribes of the Warm Springs Indian Reservation	9.0 (11.0) mg/L		
Confederated Tribes of the Colville Indian Reservation	8.0 mg/L[5]	9.5 mg/L[5]	

States are also exploring a variety of assessment approaches for instantaneous minimum DO criteria across a variety of habitats. Many states highlight the importance of taking into account the time of day for their sampling to address the minimum DO criteria. One example is Minnesota that applies a daily minimum of 5 mg O_2/L to its cool and warm water fisheries and splits the year into two seasons; May through September and October through April. Their assessment for dissolved oxygen requires no more than ten percent of the measurements taken in either period violate the standard. Furthermore, measurements must be taken before 9:00 am to be representative of minimal conditions. Similarly, Oklahoma has a criterion of 5 mg O_2/L for warm water aquatic communities, but decreases that to 4 mg O_2/L during June 16 to October 15. Impairment is cited if more than 10% of the samples are below the criterion or if more than 2 samples are below 2 mg O_2/L. Under this form of wording for impairment assessment caution is recommended basing such assessments on percent of samples such that sufficient numbers of samples are collected for representative assessments.

Kansas (2011) was considering a variety of options to updating their 5 mg O_2/L minimum DO criterion. Options include: 1) lowering the DO criterion to a 4 mg/L instantaneous minimum. 2) assessing DO as a chronic impairment with binomial statistics (10% allowance of exceedance), explicitly stating allowances accounting for natural conditions, 4) explicitly excluding applying the criterion to the deepest portions of lakes (i.e. hypolimnetic waters).

For Massachusetts, in estuaries, their analysts compare DO data to the appropriate criterion (depending on a waterbody's classification) for surface water and depth measurements. (The national criteria daily minima (1.0 mg O_2/L less than the 7-day mean) were set to protect against acute (mortality) of sensitive species and they were also designed to prevent significant episodes

of continuous or regularly recurring exposures to dissolved oxygen at or near the lethal threshold. DWM analysts use this daily minimum deviation (1.0 mg O_2/L) from the criterion for impairment decisions.) If all DO data meet (i.e., are above) the criterion, DO is considered sufficient to support the *Aquatic Life Use*. The analyst must evaluate the frequency and duration of excursions (whether or not they exceed 10% of the measurements) as well as the magnitude of any excursions (i.e., >1.0 mg O_2/L below the criterion). DO is identified as a cause of impairment if data indicate frequent, prolonged and/or severe excursion(s) from the appropriate criterion.

The temporal resolution and spatial density of measurements are variously considered across the country. In Oklahoma, for lakes, volume and space are taken into account and impairment is claimed if more than 50% of the lake water column has a dissolved oxygen concentration less than 2 mg O_2/L or if 10% of the surface samples are below the 5/4 mg O_2/L criteria.

Avoiding some of the challenges of grab sampling approaches to address temporal issues of diel cycling in DO behavior, states are advancing the uses of continuous monitoring data assessments. Washington State notes "Continuous sampling throughout the day can provide the lowest daily DO values; however, single "grab" samples are also used to determine compliance" (Department of Ecology, State of Washington 2009). Missouri evaluates stream reaches conceptually the way the Bay conducts segment assessments and also recommends continuous monitoring data assessments at representative points in the stream (Missouri DNR 2010):

> *The recommended sample size needed to estimate average daily mean and minimum DO concentrations in each of Missouri's ecological drainage units (EDU) are as follows:*
>
> 1) *Continuous DO data collection efforts should target a deployment period of 68 days during the summer sampling period (July 1 – September 30);*
> 2) *Data should be collected at 2 locations on each reference reach;*
> 3) *All reference reaches should be monitored; and,*
> 4) *Three years (summers) of data should be collected at each site.*

Rhode Island saltwater DO criteria are evaluated on cumulative exposures of low DO with established minimum standards. Therefore, Rhode Island is also moving to a reliance on continuously collected saltwater DO data or data that can correlated to continuous data. Data are not interpolated but considered based on site specific assessment representing a region of the estuary (RI State Office of Water Staff, Pers. Comm.). Grab samples or similar DO data may still be considered if it can be correlated to continuous data or is representative of a longer time period.

Delaware has recently proposed preliminary draft site specific DO criteria for tidal Murderkill River (U.S. EPA, Pers. Comm.) with an instantaneous minimum criterion as summer daily minimum (1-hour average) DO greater than or equal to 1.0 mg O_2/L. A one hour average criterion would also necessitate a dependence on continuous monitoring data. For criteria derivation, DE may be

using the following figure as their justification as well as using the calculation methods in the document.

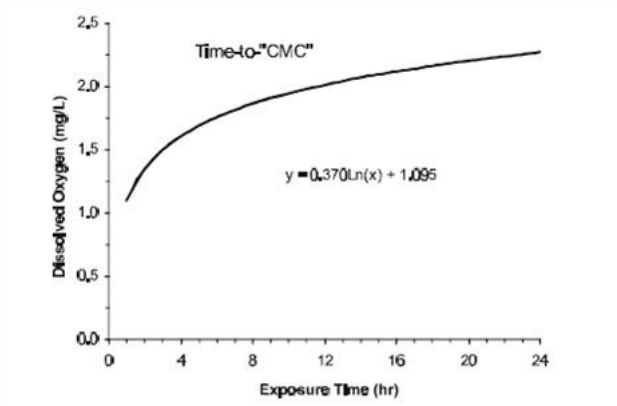

Figure 10. Criterion for juvenile saltwater animals exposed to low DO for 24 hr or less. The line represents the same protective limit as the CMC for juveniles for continuous exposure. The line is a logarithmic expression with a slope and intercept calculated from the regressions in Figure 9 at the DO concentration of 2.3 mg/L (the CMC).

United States EPA (2000). Office of Water 4304 EPA-822-R-00-012 November 2000 Ambient Aquatic LifeWater Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras.

The Chesapeake Bay Instantaneous Minimum Workshop

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

Through the Chesapeake Bay Program's Umbrella Criteria Assessment process, representatives of the Chesapeake Bay Program partnership expressed concerns about the definition and assessment of the instantaneous minimum criteria in Chesapeake Bay tidal waters. The Chesapeake Bay Program partnership, working through its Science, Technical Assessment and Reporting Team's Criteria Assessment Protocol Workgroup, requested an opportunity to review

the existing instantaneous minimum criteria with its assessment protocols and explore potential alternative interpretations. The Criteria Assessment Protocol Work Group worked with the Tidal Monitoring and Assessment Workgroup of the Science, Technical Assessment and Reporting Team at the Chesapeake Bay Program and scheduled a workshop for October 2013. The objectives of the workshop are:

1) To review the existing application of the instantaneous minimum criteria as applied to water quality standards attainment assessments in the tidal waters of Chesapeake Bay.
2) To review the assessment of instantaneous minimum criteria as applied to water quality standards attainment assessments in the tidal waters of Chesapeake Bay
3) To develop science-based recommendations for consideration by the Chesapeake Bay Program partnership of alternative interpretations of the instantaneous minimum criterion definition, alternative short-duration criteria, and coincident options for their procedures supporting their assessment.