Chesapeake Bay Program | Indicator Analysis and Methods Document

Water Quality Standards Achievement

Updated July 2021

Indicator Title: Water Quality Standards Achievement

Relevant Outcome(s): Water Quality Standards Attainment and Monitoring

Relevant Goal(s): Water Quality

Location within Framework (i.e., Influencing Factor, Output or Performance): Performance

A. Data Set and Source

(1) Describe the data set. What parameters are measured? What parameters are obtained by calculation? For what purpose(s) are the data used?

Parameters necessary to compute Chesapeake Bay water quality standards for dissolved oxygen, water clarity (m) and chlorophyll are:

- Salinity (unitless),
- water temperature (T in ºC),
- dissolved oxygen (DO in mg O_2/L),
- Secchi depth (m),
- submerged aquatic vegetation (SAV) acreage,
- *in vivo* fluorescence, and
- chlorophyll *a* measurements (ug/L).

Salinity and water temperature are necessary to compute the vertical density structure of the water column (i.e. the top and bottom of the pycnocline, when they exist). Water column structure is translated into designated use layers for open water, deep water and deep channel designated use boundaries of the dissolved oxygen attainment assessments when boundaries can be defined (Figure 1).

The attainment indicator presently uses a subset of the criteria otherwise necessary for a complete regulatory accounting of water quality standards attainment assessments of tidal water Chesapeake Bay dissolved oxygen, water clarity and chlorophyll a (Figure 2). The indicator, therefore, is recognized as an estimate of true attainment of these water quality standards. For example, in order to be in attainment for the open water designated use (see Figure 1) in a particular management segment of the Bay (Figure 3), attainment requires simultaneously meeting 3 conditions: a 30-day mean condition, a 7-day mean condition and an instantaneous condition. Presently we only interpret the open water 30-day mean for attainment of the open water dissolved oxygen assessment. However, in 2010, a rule was put in place based on model analyses to suggest that if we meet the 30-day mean, we also are meeting the 7-day and instantaneous criteria. Season-specific criteria can also apply.

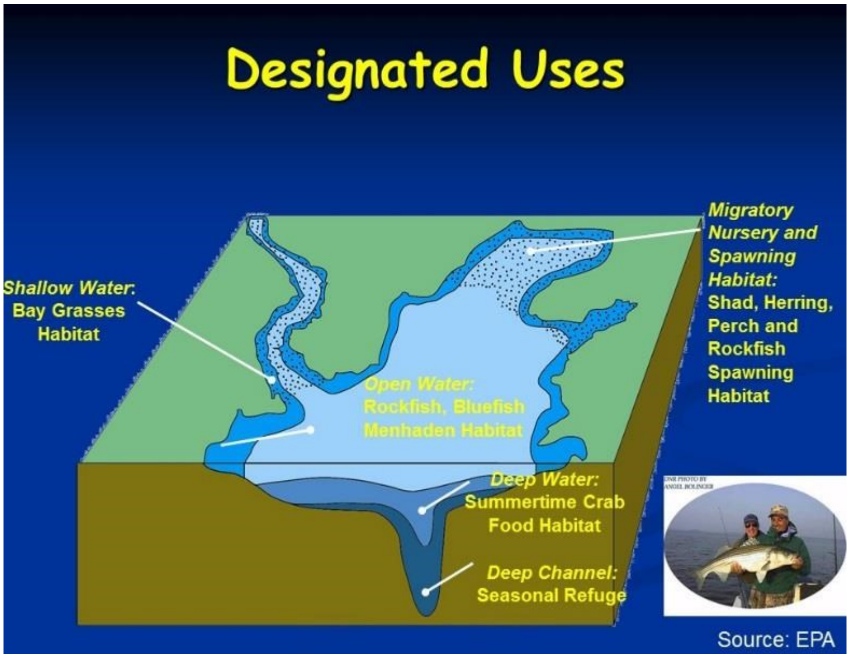

Figure 1. The 5 designated uses that apply to the Chesapeake Bay Multimetric Water Quality Standards Attainment Indicator analysis.

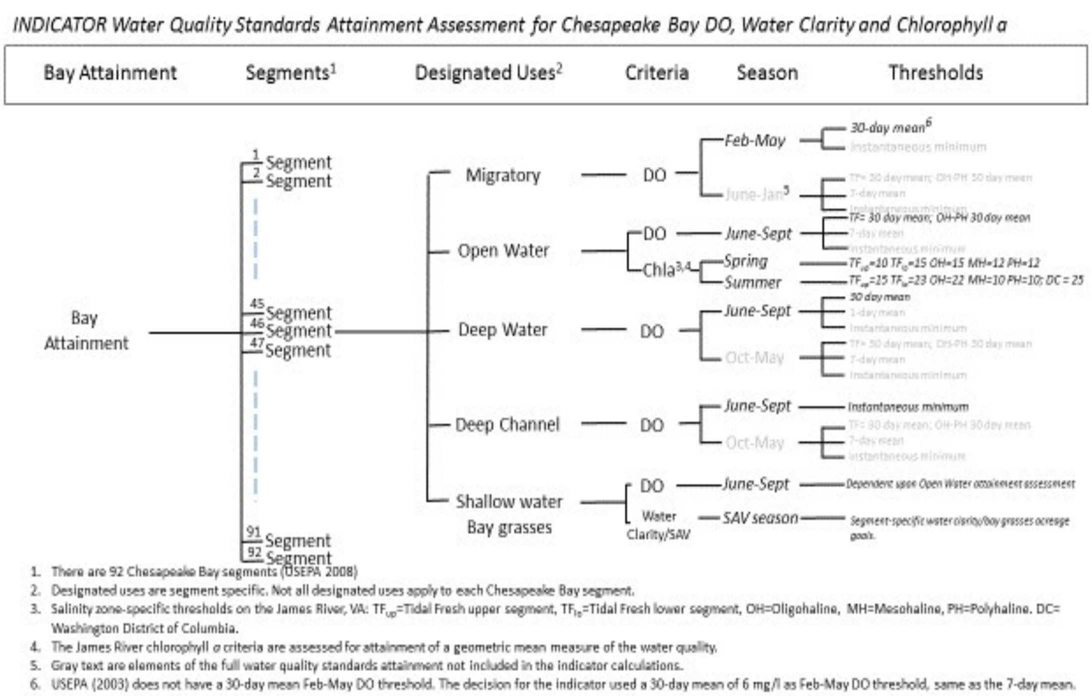

Figure 2. The Multimetric Water Quality Standards Attainment (MWQS) indicator assessment is a stripped down version of the complete water quality standards attainment assessment. **Gray text** documents standards measures that exist but are not measured or reported on and to-date, excluded from the indicator calculations.

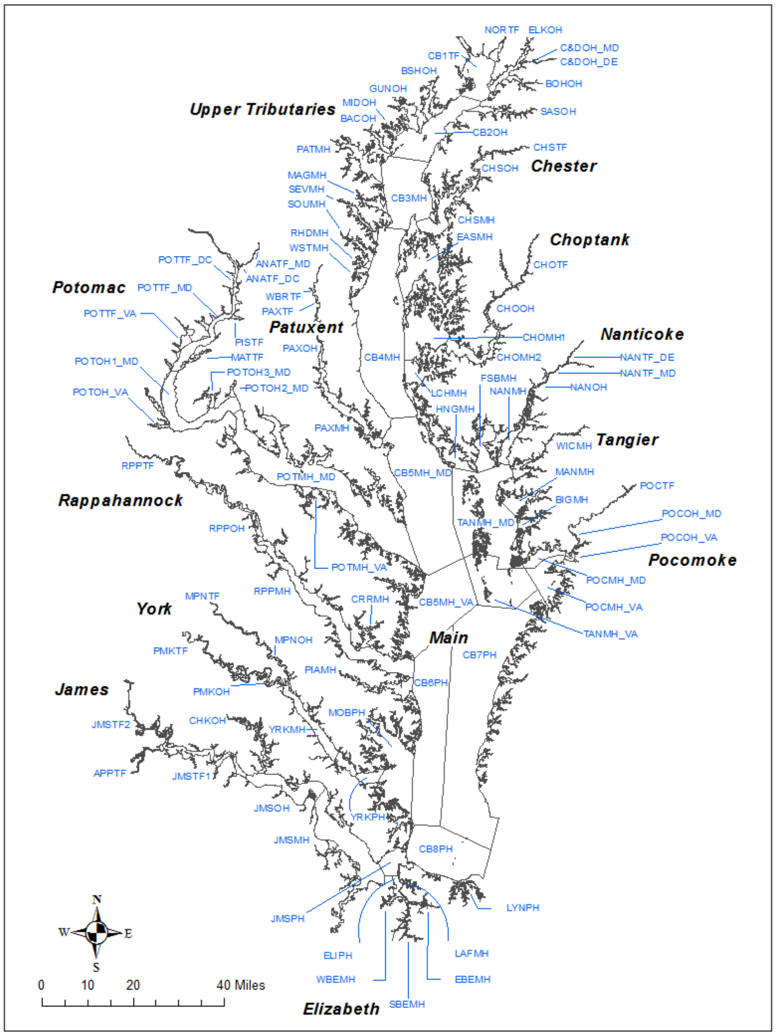

Figure 3. A map of the 92 Chesapeake Bay segments assessed for attainment status in the MWQS Attainment Indicator analysis.

Parameter data are derived as follows:

- Salinity is directly measured with a probe.
- Water Temperature is directly measured with a probe.
- Dissolved oxygen is directly measured with an optical probe unless otherwise described by the data source.
- Secchi depth is directly measured with a Secchi disc.
- Chlorophyll *a* is measured in two ways:
  - discrete, fixed station-based water samples collected and laboratory analysis of chlorophyll *a* levels, and
  - a fluorometric probe that measures the *in vivo* fluorescence values during DATAFLOW operations. (DATAFLOW is high-speed, high temporal density water quality mapping method measuring the water quality approximately 1 meter below the surface.) During the course of the water quality mapping process, the boat is periodically stopped. Water samples are collected at 1 meter below the surface at these locations and identified

with their date, location and time. The water samples collected at these locations are processed in the laboratory through an extractive process for determining their chlorophyll *a* measurements. The extractive chlorophyll *a* results are then paired with the *in vivo* fluorescence values at the same date, time and location. The results are plotted on a graph and a linear equation representing the relationship between chlorophyll *a* and *in vivo* fluorescence values is produced. The relationship is not constant across all conditions which is why this is done each day. The results represent the instrument calibration for measuring chlorophyll *a* for that day and area. The daily calibration curves and their equations provide the tools for a translation for all the DATAFLOW fluorometry measurements into best estimates of the chlorophyll *a* values.

- SAV acreage – calculated from aggregations of photo-interpreted SAV area data to segment, zone and bay-wide levels.

- Purpose: The uses of the water quality data include: meeting Clean Water Act 303d listing requirements, tracking and accountability towards assessing progress in Chesapeake Bay restoration as it relates to meeting outcomes of the 2014 Chesapeake Watershed Agreement, research support, water quality modeling calibration and verification data sets supporting the Chesapeake Bay TMDL.

  The Multimetric Indicator is an indicator of, but not equivalent to a full accounting for, water quality standards attainment status and trends taken in combination for dissolved oxygen, water clarity, and chlorophyll *a*.

(2) List the source(s) of the data set, the custodian of the source data, and the relevant contact at the Chesapeake Bay Program.

- Source:
  Salinity, water temperature, DO, Secchi depth and chlorophyll *a* are measured by the MD Department of Natural Resources (MD mainstem and tributary data), the VA Department of Environmental Quality (VA tributary data and benthic monitoring data), Old Dominion University (VA mainstem data), Virginia Institute of Marine Sciences (VA tributary data), and submitted citizen/volunteer monitoring data (VA tributary data, South River Federation, MD). SAV area is measured by Virginia Institute of Marine Science (VIMS).

  DO and chlorophyll *a* assessments are conducted at CBPO by Richard Tian (UMCES-CBPO). Water clarity/SAV assessments are conducted by the Maryland Department of Natural Resources (Mark Trice), Virginia Institute of Marine Science (Dave Parrish), and Virginia DEQ (Tish Robertson).

- Custodian:

- For raw data: Mike Mallonee (ICPRB-CBPO)
- For DO and chlorophyll *a* assessments: Richard Tian (UMCES-CBPO)
- For SAV acreage data: Chris Patrick (VIMS) or David Wilcox (VIMS)

- For Water clarity assessments: Dave Parrish (VIMS) (VA) or Tish Robertson (VADEQ) (VA) and Mark Trice (MDDNR) (MD)

- Chesapeake Bay Program Contact (name, email address, phone number):
  Qian Zhang (UMCES-CBPO); qzhang@chesapeakebay.net; (410) 267-5794
  Richard Tian (UMCES-CBPO); rtian@chesapeakebay.net; (410) 295-1328
  Peter Tango (USGS-CBPO); ptango@chesapeakebay.net; (410) 267-9875

(3) Please provide a link to the location of the data set. Are metadata, data-dictionaries and embedded definitions included?

Data:

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

Assessments:

- DO and chlorophyll *a* assessment results can be obtain by contacting Richard Tian, CBPO (rtian@chesapeakebay.net).
- Water clarity attainment results may be obtained by contacting Dave Parrish (parrishd@vims.edu) at VIMS or Tish Robertson (tlrobertson@deq.virginia.gov) at VADEQ for the VA results and Mark Trice (MTrice@dnr.state.md.us) at MDDNR for the MD results.

B. Temporal Considerations

(4) Data collection date(s): 1985-2019

(5) Planned update frequency (e.g., annual, biannual, etc.):
- Source Data: Annual
- Indicator: Annual

(6) Date (month and year) next data set is expected to be available for reporting:
- Raw data are available in the spring of the following year.
- DO and chlorophyll *a* assessments are available in the spring of the following year.
- SAV data is available in the spring of the following year.
- Water clarity assessments, when conducted, are available in the fall of the following year.

C. Spatial Considerations

(7) What is the ideal level of spatial aggregation (e.g., watershed-wide, river basin, state, county, hydrologic unit code)?

- DO and SAV data are aggregated to 92 tidal water segments for the Chesapeake Bay (2008 revised Chesapeake Bay Program segmentation scheme: http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).
- Chlorophyll *a* data are aggregated to the 7 tidal water segments for which numeric criteria apply (5 segments in the James River, 2 segments in Washington DC tidal waters of the Potomac River watershed).
- Water clarity data are aggregated to each tidal water segment where the shallow-water monitoring (i.e., continuous monitoring) is active. This presently occurs in some small subset of the 92 segments each assessment period.

(8) Is there geographic (GIS) data associated with this data set? If so, indicate its format (e.g., point, line polygon).

Point data are used to create interpolated surface or volumes of water quality condition. The analysis of those interpolations is used to evaluate water quality standards attainment status for dissolved oxygen, water clarity/SAV, and chlorophyll *a* at the Chesapeake Bay segment level, which is a polygon.

(9) Are there geographic areas that are missing data? If so, list the areas.

No.

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

Examples of maps of yes/no in attainment for each segment and designated use have been available online with the Chesapeake Bay Program Office, e.g., https://www.chesapeakebay.net/what/maps/chesapeake_bay_waters_meeting_chlorophyll_a_criteria_water_quality_goal1.

D. Communicating the Data

(11) What is the goal, target, threshold or expected outcome for this indicator? How was it established?

Water quality standards describe the goals or designated uses for a waterbody and the criteria or water quality measures necessary to protect those uses. For the Bay and its tidal tributaries to function as a healthy ecosystem, 100% attainment of these standards must be met. Water quality standards attainment for this purpose is determined by a subset of three key measures affecting habitat health in the tidal waters of Chesapeake Bay: dissolved oxygen (DO), water clarity/SAV and chlorophyll *a*. The indicator was established to provide an estimated measure of status and progress towards achieving attainment of DO, water clarity/SAV and chlorophyll *a* as outlined in the 2010 USEPA Total Maximum Daily Load (TMDL) for Chesapeake Bay and further refined during the 2017 mid-point assessment.

This indicator does not include a full accounting of the year of water quality standards attainment for dissolved oxygen, water clarity/SAV and chlorophyll *a* as stated by state regulations. In addition, attainment as measured by this indicator does not mean all other water quality standards being assessed in an area are similarly in attainment. Such other parameters which may be recognized in a regulatory context as impairing water quality in the bay ecosystem include but may not be limited to bacteria, toxics, pH, temperature or ambient living resources (e.g., benthic index of biotic integrity).

(12) What is the current status in relation to the goal, target, threshold or expected outcome?

The current Bay-wide attainment score is 33.1%, meaning that 33.1% of bay tidal waters are in estimated attainment of water quality standards during the 2017 – 2019 assessment period.

(13) Has a new goal, target, threshold or expected outcome been established since the last reporting period? Why?

No.

(14) Has the methodology of data collection or analysis changed since the last reporting period? How? Why?

The framework of the methodology has remained the same. However, two major updates were made to the 2013-2015 assessment period to apply to the full time series to more accurately reflect the intent of the framework methods. These updates are described in detail in question 37.

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

The bay-wide summary score for the indicator shows results are varying in a small band of scoring over time ranging between 26.1 and 42.2 percent. Periods of improvement and decline correlate with significant climatic events in the region. For a little over a decade long period in the early part of the time series there is a trend showing improvement. After a peak that coincided with the 1999-2002 drought, the indicator value trended downward consistent with the impacts of Hurricane Isabel in 2003. Due to an annual rolling three-year assessment, the downward trending effects of Hurricane Irene and Tropical Storm Lee in 2011 were keeping indicator values low through the 2011-2013 period. The pace of recovery should be assessed to look at rate of resilience such that as stresses on the system are reduced through restoration management, recovery rates from such climate impacts should improve. The most recent years have trended upward as the bay health recovered from the storm impacts, particularly SAV acreages and dissolved oxygen conditions, resulting in the 2015-2017 period achieving the highest attainment status in the entire record. Unusually wet weather in 2018 led to a consecutive decline in the assessment status for 2016-2018 and 2017-2019.

Overall, the indicator has a positive and statistically significant trend between 1985-1987 and 2017-2019, which shows that Chesapeake Bay is on a positive trajectory toward recovery. This pattern was statistically linked to total nitrogen reduction, indicating responsiveness of attainment status to management actions implemented to reduce nutrients (Zhang et al., 2018). Patterns of attainment of individual designated uses are variable. According to Mann-Kendall trend analysis extended from a publication (Zhang et al., 2018, see https://doi.org/10.1016/j.scitotenv.2018.05.025), dissolved oxygen attainment (including open water and deep channel) and water clarity/SAV attainment showed statistically significant improvements between 1985-1987 and 2017-2019, which may be an indication of increasing resilience in the bay ecosystem since the Bay restoration began.

(16) What change(s) does the most recent data show compared to the last reporting period? To what do you attribute the change? Is this actual cause or educated speculation?

A consecutive decline in attainment indicator occurred during the 2016-2018 and 2017-2019 assessment periods down from the record high of 42.2% during the 2015-2017 assessment period. However, given that 2018 was the highest-flow year since at least 1937 (refer to https://www.usgs.gov/centers/cba/science/freshwater-flow-chesapeake-bay), the decline was anticipated. Declines in dissolved oxygen (mainly deep channel and deep water) and chlorophyll *a* impacted the attainment results between 2016-2018 and 2017-2019, potentially reflecting short-term fluctuations in precipitation and associated river inputs. These declines were associated with a few large segments with very minor levels of attainment deficit; therefore, the attainment values are expected to rebound in next assessment periods as the effects of the unusually wet weather in 2018 diminish. On a positive note, despite the highest flow in 2018, open water dissolved oxygen has actually improved in the 2017-2019 assessment period over the preceding assessment period.

(17) What is the key story told by this indicator?

This indicator estimates the percentage of Chesapeake Bay tidal waters that meet the water quality standards necessary to protect aquatic habitats and determine the effectiveness of our management actions. Water quality standards attainment for this purpose is determined by combining three key water quality measures from all the monitored water quality data affecting habitat health in the tidal waters of

Chesapeake Bay: dissolved oxygen (DO), water clarity/underwater grasses (SAV) and chlorophyll *a* (a measure of algae growth).

E. Adaptive Management

(18) What factors influence progress toward the goal, target, threshold or expected outcome?

- Understanding the factors affecting the ecosystem response to pollutant load reductions to focus management efforts and strategies;
- Understanding the intensity of actual management efforts to reduce pollutant loads to levels predicted to provide the anticipated water quality responses;
- Delivering the necessary financial capacity to implement practices and programs;
- Factoring in effects from continued climate change;
- Addressing the impact of reduced sediment storage capacity of the lower Susquehanna River dams, specifically Conowingo Dam, have on the pollutant loads to the Bay;
- Addressing BMP implementation, including:
  - Shoreline development,
  - Wetland abundance, distribution and health,
  - Nutrient management;
- Addressing invasive species issues and impacts to the Bay;
- Addressing toxics issues and impacts to the Bay;
- Addressing living resource management, e.g., filter feeder communities that can filter algae, sequester carbon and improve water quality conditions;
- Enhancing stewardship of the watershed and Bay.

The watershed model accounts for changes in conditions in the watershed that can yield increases or decreases in nutrient loads and erosion to local water bodies and, in turn, to tidal waters of the Bay. The changes in conditions through time are updated yearly based on new data or projections from historic data. The conditions include, but are not limited to, the following:

- Land use and land cover types and acres;
- Crop types, acres and yields;
- Animal populations, weight, and their manure and litter nutrient concentrations;
- Chemical fertilizer sales and use;
- Human population and housing;
- Septic systems;
- Atmospheric deposition of nitrogen.

(19) What are the current gaps in existing management efforts?

Considering the above-listed factors influencing progress toward the goal, target, threshold or expected outcome, the following gaps have been identified in existing monitoring and management efforts to support tracking changes towards achieving a restored Bay:

- Addressing aging infrastructure for handling wastewater and stormwater runoff given existing conditions and future climate projections for increased precipitation in the region;
- Addressing maximum infill capacity leading to dynamic equilibrium conditions now at the Conowingo Dam affecting nutrient delivery to the estuary;
- Balancing population growth with collective impacts of growth on nutrient delivery and other factors (e.g., local, regional, and national temperature conditions impacting water temperature and DO saturation conditions);
- Managing trophic structure of the Bay that can affect nutrient processing and the expression of the eutrophication signal;
- Restoring filter feeder populations and SAV populations;
- Maintaining or enhancing wetlands and wetland filtering and nutrient retention capacity;
- Monitoring and understanding the effect of invasive species on trophic structure, e.g., blue catfish abundance and distribution and the resulting diet requirements of this large and expanding fish population;
- Monitoring and classifying wetland habitat and providing condition status with a reliable method for tracking status and change of wetland habitats in the bay watershed;
- Monitoring and understanding effectiveness and life cycle of many BMPs;
- Enhancing riparian buffer development that serves to cool streams with shade and retain nutrient and sediment runoff from reaching waterways;
- Limiting shoreline hardening affecting restoration capacity for the Bay;
- Incorporating societal perspectives and lifestyle choices that reflect on stewardship of the bay and influence business, industry and personal behaviors resulting in effects on environmental and personal health and well-being.

Based on the Chesapeake Bay Program Partnership's suite of modeling tools, states have taken their Bay TMDL allocations and developed Watershed Implementation Plans to meet the 2025 water quality outcome of "By 2025, have all practices and controls in place to achieve applicable water quality (i.e., dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll a) standards as articulated in the Chesapeake Bay Total Maximum Daily Load (Bay TMDL)." Monitoring data resolution affects the power to detect trends that corroborate or inform modeling results to determine if all partners are on track to achieve these water standards. High temporal frequency data can identify a trend more readily than low temporal frequency data where there is greater uncertainty surrounding the estimation of the conditions. States may choose to invest more monitoring resources in places were low data density already suggests strong progress or strong, unanticipated degradation in order to de-list waters in an area sooner or change the management strategy where perhaps previously unidentified factors are now dominating the influence on the trend.

While monitoring data resolution can enable trend detection more readily, there is still a need to manage expectations for environmental change in time. Understanding from experience that restoration and recovery at large scales takes time, communities can track local scale changes that reflect the more immediate response to management actions and different levels of system response. Enhanced monitoring can detect the trend earlier but the larger response in the ecosystem recovery may still take a relatively long time. Thus, the Partnership seeks to manage expectations about how quickly the system may respond and at what scale changes can be detected.

(20) What are the current overlaps in existing management efforts?

N/A

(21) According to the management strategy written for the outcome associated with this indicator, how will we (a) assess our performance in making progress toward the goal, target, threshold or expected outcome, and (b) ensure the adaptive management of our work?

(a) Water quality standards attainment is assessed in 3-year periods with reporting requirements under the Clean Water Act between the States/the District of Columbia and the U.S. EPA. The multimetric indicator provides one number that reflects an estimate of the health status of the bay. Trend assessment is applied to assess change over time and space for water quality standards attainment in the tidal waters of the Bay.

As products of the Bay TMDL's midpoint assessment information decision-support needs, the CBP Partnership worked to enhance the analysis and explanation of monitoring information. The CBP partners have endorsed (PSC, May 2012) an integrated approach that includes three primary pieces of information to measure progress toward water quality standards:

- Reporting of water quality management practices. (See information associated with the Reducing Pollution Indicator in Chesapeake Progress.)
- Analyzing trends of nitrogen, phosphorus and sediment in the watershed. Supporting literature for reference now includes:
  - Moyer, D.L. and M.J. Langland, 2020. Nitrogen, phosphorus, and suspended-sediment loads and trends measured at the Chesapeake Bay Nontidal Network stations: Water years 1985-2018: U.S. Geological Survey data release, https://doi.org/10.5066/P931M7FT.
  - Zhang, Q. and J.D. Blomquist. 2018. Watershed export of fine sediment, organic carbon, and chlorophyll-a to Chesapeake Bay: Spatial and temporal patterns in 1984-2016. Science of the Total Environment. 619-620: 1066-1078.
  - Zhang, Q., D.C. Brady, W.R. Boynton, and W.P. Ball. 2015. Long-Term Trends of Nutrients and Sediment from the Nontidal Chesapeake Watershed: An Assessment of Progress by River and Season, Journal of the American Water Resources Association. 51(6): 1534-1555.

- o Assessing attainment of dissolved oxygen, chlorophyll and water clarity/SAV standards. Supporting literature for reference now includes:
    - Hernandez, A., P. Tango, R. Batiuk. 2020. Development of the Multi-metric Water quality indicator. Environmental Management and Assessment. 192:94-110.
    - Zhang, Q., P. Tango, R.R. Murphy and others. 2018. Attainment Deficit: Three decades of Temporal and Spatial Patterns in Chesapeake Bay Dissolved Oxygen Criterion Nonattainment. Frontiers in Marine Science. 5:422.
    - Zhang, Q., R.R. Murphy, R. Tian, M. K. Forsyth, E. M. Trentacoste, J. Keisman, and P.J. Tango. 2018. Chesapeake Bay's water quality condition has been recovering: Insights from a multimetric indicator assessment of thirty years of tidal monitoring data. Science of the Total Environment. 637-638: 1617-1625.

In addition, the following activities are elements of annual work plans, STAC workshops and publications producing outputs within the CBP including:

- o Analyze water quality trends in the Bay and its watershed. See "Projects and Resources" of the Integrated Trends Analysis Team and USGS results for watershed trend assessments.
- o Explain the factors affecting water quality trends in Bay and its watershed.
- o Enhance CBP models using the improved understanding of trends.

(b) Adaptive Management: The CBP partnership is following an adaptive management decision framework (see figure to right).
By following the prescription of the cycle, the CBP will continue to examine the following questions to address implementation challenges and opportunities, incorporate new data and scientific understandings and refine decision support tools and management strategies toward the achievement of the water quality outcomes in the *2014 Chesapeake Bay Watershed Agreement*:

- o What progress had been made in implementing practices for the Bay TMDL?
- o What are the changes in water quality and progress toward applicable water quality standards?

- What are we learning about the factors affecting water quality changes to better implement practices?
- What refinements are needed in decision support tools, monitoring and science?
- How do we best consider the combined impacts of land change and climate variability (storm events and long-term change) on nutrient and sediment loading and implications for the Bay TMDL?

F. Analysis and Interpretation

Please provide appropriate references and location(s) of documentation if hard to find.

(22) What method is used to transform raw data into the information presented in this indicator? Please cite methods and/or modeling programs.

The logic of pycnocline application for determination of designated uses was corrected, in order to allow for episodic occurrence of deep-water and deep-channel designated uses. These refinements are described in the Technical Addendum published in May 2010 and are available at http://www.chesapeakebay.net/content/publications/cbp_51366.pdf.

The published dissolved oxygen criteria assessment methodology currently used for assessing Chesapeake Bay water quality criteria attainment involves the use of cumulative frequency distribution (CFD) curves in a 2D space of percent time and percent space to determine the extent of compliance. The most recent updates for the procedure for assessing dissolved oxygen criteria attainment are described in detail in Appendix A of the September 2008 water quality criteria addendum: *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries 2008 Technical Support for Criteria Assessment Protocols Addendum* (http://www.chesapeakebay.net/content/publications/cbp_47637.pdf).

In 2004, Virginia and the District of Columbia adopted numerical chlorophyll *a* criterion for application in the tidal James River and across the District's jurisdictional tidal waters. In 2007, EPA provided states guidance for the assessment of chlorophyll *a* criteria through the publication of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2007 Chlorophyll Criteria Addendum* (http://www.chesapeakebay.net/content/publications/cbp_20138.pdf). The following list of resources address the background regarding assessment methods of chlorophyll *a* criterion in Chesapeake Bay and its tidal tributaries:

1) USEPA 2003. Original Criteria document. Interpolation and CFD assessment of criteria are outlined here. http://www.chesapeakebay.net/content/publications/cbp_13142.pdf
2) USEPA 2007. The Chlorophyll criteria addendum. Documented the scientific basis for numerical criteria and recommendations for monitoring and

assessment.
http://www.chesapeakebay.net/content/publications/cbp_20138.pdf

3) USEPA 2008. Technical Support for Criteria Assessment. Please see Chapter 5 and then the step by step guide in Appendix G, Chlorophyll criteria assessment method. http://www.chesapeakebay.net/channel_files/20963/2008_addendum_ambient_water_quality_criteria.pdf
4) USEPA 2010. Please see Chapter 4, Revisions to the Chlorophyll Criteria Assessment Methodology, Pp 31-38. http://www.chesapeakebay.net/content/publications/cbp_51366.pdf

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

ArcGIS geodatabase in a Universal Transverse Mercator (UTM) Zone 18 projection was used to calculate area in square meters for all SAV beds. Please see the SAV indicator and accompanying Analysis & Methods document for more information.

Rules supporting presentation and interpretation of the indicator:
For the presentation of this indicator, we assumed that attainment of the **30-day mean** dissolved oxygen criterion can serve as an "umbrella" assessment to the remaining criteria applicable to its designated use. This means, by rule, that when the 30-day mean passes its criterion, it is indicative of other shorter duration criteria also passing their criteria and is therefore protective of the full designated use. In this way, we are able to fully assess attainment across all segments, uses and criteria. The full set of rules used in this way are as follows:

- Migratory Fish and Spawning Nursery Habitat: applied the 30-day mean to represent protections as if it were the 6 mg/L 7-day mean DO criterion.
- Open-Water Fish and Shellfish Habitat: 5 mg/L 30-day mean DO criteria.
- Deep-Water Seasonal Fish and Shellfish Habitat: 3 mg/L 30-day mean DO criteria.
- Deep-Channel Seasonal Refuge Habitat: 1 mg/L instantaneous minimum DO criteria.
- Shallow-Water Bay Grasses Habitat:
  When water clarity assessment data are available, the shallow-water bay grasses designated use is considered in attainment if:
  1. sufficient acres of SAV are observed within the segment; or
  2. enough acres of shallow-water habitat meet the applicable water clarity criteria to support restoration of the desired SAV acreage for that segment.

- Chlorophyll *a* numeric criterion as it applied to the open-water designated use for the mainstem James River segments and the District of Columbia's Upper Potomac River and Anacostia River segments:
  - James River segments: Criteria attainment assessed during spring (Mar 1 – May 31) and summer (Jun 1 – Sep 30) seasons; both seasons must be meeting the standards for the segment to be in attainment.
  - District of Columbia's Upper Potomac River and Anacostia River segments: Criteria attainment only assessed during the summer (Jun 1 – Sep 30) season.

Impairment determinations were then summarized for every applicable designated use and criteria contained within each of the 92 segments. Using a surface area-weighted approach, which multiplies the open water surface area of each of the 92 segments times the number of applicable designated uses for that segment, this indicator factors in the number of designated uses and relative size of each segment, ensuring we report the best available measure of how much of the Bay tidal waters are achieving water quality standards. At the same time, this approach gives equal weight to achievement of the criteria protective of each designated use and segment.

(23) Is the method used to transform raw data into the information presented in this indicator accepted as scientifically sound? Yes. If not, what are its limitations? N/A

(24) How well does the indicator represent the environmental condition being assessed?

This indicator uses the best available information used by the jurisdictions in reporting Clean Water Act 303d listing assessments of impaired waters for Chesapeake Bay. However, the assessment approach has limitations due to small sample sizes which provides more uncertainty about the actual state of the system than larger samples and greater spatial coverage could otherwise accomplish.

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

Yes. Water quality criteria for the Chesapeake Bay and its tidal tributaries used for the assessment of water quality standards have been developed and published (2003) through the range of Chesapeake Bay water quality criteria publications located at http://www.chesapeakebay.net/content/publications/cbp_13142.pdf. The following information was included in the 2007 addendum to the *2003 Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll a*. The 2007 addendum is available at http://www.chesapeakebay.net/publications/title/ambient_water_quality_criteria_for_dissolved_oxygen_water_clarity_and_2.

Chlorophyll *a* goals for Virginia James River.*

bb. The following site specific numerical chlorophyll a criteria apply March 1 through May 31 and July 1 through September 30 as seasonal means to the tidal James River (excludes tributaries) segments JMSTF2, JMSTF1, JMSOH, JMSMH, JMSPH and are implemented in accordance with subsection D of 9VAC25-260-185.

Designated Use	Chlorophyll a μ/l	Chesapeake Bay Program Segment	Temporal Application
Open Water	10	JMSTF2	March 1 - May 31
	15	JMSTF1	
	15	JMSOH	
	12	JMSMH	
	12	JMSPH	
	15	JMSTF2	July 1 - September 30
	23	JMSTF1	
	22	JMSOH	
	10	JMSMH	
	10	JMSPH	

*Note, criteria for Washington DC waters is 25 ug/L, summer season mean.

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

Three-year periods are highly variable, so extrapolation is not feasible.

G. Quality

Please provide appropriate references and location(s) of documentation if hard to find.

(27) Were the data collected and processed according to a U.S. Environmental Protection Agency-approved Quality Assurance Project Plan? If so, please provide a link to the QAPP and indicate when the plan was last reviewed and approved. **If not, please complete questions 28-30.**

Yes, methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA CBPO tidal waters 117e monitoring grants to the Maryland Department of Natural Resources and Virginia Department of Environmental Quality. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

(28) *If applicable:* Are the sampling, analytical and data processing procedures accepted as scientifically and technically valid?

See #27.

(29) *If applicable:* What documentation describes the sampling and analytical procedures used?

See #27.

(30) *If applicable:* To what extent are procedures for quality assurance and quality control of the data documented and accessible?

See #27.

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

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

(32) Were the sampling, analytical and data processing procedures performed consistently throughout the data record?

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

Some technical improvements (e.g., photo-interpretation tools) were made over the 26 years of the annual SAV survey in Chesapeake Bay.

Please see the SAV indicator and accompanying Analysis & Methods document for more information at http://www.chesapeakeprogress.com/abundant-life/vital-habitats/sav.

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

(33) If data sets from two or more sources have been merged, are the sampling designs, methods and results comparable? If not, what are the limitations?

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

(34) Are levels of uncertainty available for the indicator and/or the underlying data set? If so, do the uncertainty and variability impact the conclusions drawn from the data or the utility of the indicator?

There is not an explicit measure of uncertainty associated with computing the value of this indicator. Measurement uncertainty is evaluated through replicate assessments for chlorophyll *a*. DO measurement uncertainty is associated with the instrument reported limits on the value. Methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA grant. Documentation is available at http://www.chesapeakebay.net/about/programs/qa/tidal.

There are daily, seasonal and annual levels of variability in time that can apply for each parameter, and spatial variability exists in the values over a region. Increased intensity of sampling in space and/or time provides improved accounting of the variability and reduces uncertainty for the condition assessment. The sensitivity of the indicator to detect change improves with better data density.

(35) For chemical data reporting: How are data below the Minimum Detection Level (MDL) reported (i.e., reported as 0, censored, or as < MDL)? If parameter substitutions are made (e.g., using orthophosphate instead of total phosphorus), how are data normalized? How does this impact the indicator?

If samples were below the MDL of the equipment, they would be reported and used in these analyses at the MDL.

The MDL for chlorophyll *a* in the Chesapeake Bay Program data collection is 1 ug/L. Different labs have different methods of reporting actual MDL values. For the database, all data below the MDL are reported as < MDL which would be the 1 ug/L. Note, the tidal water quality labs (CBL, ODU and DCLS) provide below MDL values or “BMDL” values for chlorophyll *a* that correspond to the actual instrument readings. These BMDL data are obtained by special request from Mike Mallonee and are not available through the Chesapeake Information Management System (CIMS) data hub. (Mary Ellen Ley, Pers. Comm.)

For DO, Virginia and Maryland report all values that the meter reads, down to zero. These results are available on the CIMS data hub. (Mary Ellen Ley, Pers. Comm.)

(36) Are there noteworthy limitations or gaps in the data record?

Noteworthy gaps only apply to the underlying SAV acreage data– due to funding constraints, no SAV survey was conducted in 1988. For further detail on SAV spatial gaps since 1988, refer to the analysis and methods documentation for SAV available for download at http://www.chesapeakeprogress.com/abundant-life/vital-habitats/sav.

Clarity acres measurements occur only in certain years for certain subset of the 92 segments each year. The program has planned to map the Bay in 3-year increments.

H. Additional Information (Optional)

(37) Please provide any further information you believe is necessary to aid in communication and prevent any potential misrepresentation of this indicator.

Two major updates were made to the 2013-2015 assessment period to apply to the full time series to more accurately reflect the intent of the framework methods.

(i) The application of water clarity acreage data was expanded to all applicable years.

Actual 3-year 303d list assessments reported by the States to USEPA are done in sequential, non-overlapping blocks of years. This means that a time series of 303d listing assessments appears as 2008-2010, 2011-2013, 2015-2017, etc. However, the data that go into supporting the calculations of the 303d listing assessments are available every year. By contrast, the indicator uses all available data to compute an annual update based on the most recent 3 years of data. This indicator produces values for a rolling 3-year series, i.e., 2008-2010, 2009-2011, 2010-2012, 2011-2013, etc. Since the indicator assessment has a rolling annual assessment, the monitoring in a particular segment for water clarity acres may take place for 1, 2 or 3 years because the indicator splits up the 303d listing time series blocks.

A second reason the indicator may end up computing a value for 3 years using only 1 or 2 years of water clarity acres information relates to the water quality standards attainment decision rules for meeting or failing the water clarity standard. Under the attainment decision rules, a segment may meet its water clarity goal in two ways – it can meet on SAV acreage alone, or it can meet attainment using water clarity acres. When a segment meets its goal in year 1 or 2 of a 3-year 303d listing assessment period, the rule is that the segment has met its goal for the 3-year period (best of 3 years is the comparison to the goal for attainment assessment with water clarity), and therefore the monitoring can move on to another segment. That means a segment could have only 1 year of water clarity acreage assessment. For a 303d listing assessment, that year affects one 3-year block of results reported to EPA. For the indicator, because it has an annual increment and is calculated as a rolling average, that single year will affect 3 consecutive 3-year blocks in the indicator time series because each year after the first 2 in the time series will be included in 3 years of rolling 3-year assessments.

(ii) For the DO-designated uses, nothing changed in the attainment assessment methodology. However, there have been some cruise date corrections. The cruise date updates revise the time series results for the DO assessments. This effort to get sampling dates correctly assigned with their cruises corrected some specific events.

Previously, in months with two water quality cruises, the monitoring data were separated with a default decision rule: the cruise results were separated into the first and second cruise by the 15th of the month. This decision-rule resulted in some unintended cases where data was missing in the interpolation procedures affecting pycnocline definitions and spatial attainment assessments. Therefore, the cruise list was modified as appropriate according to its connection to a specific cruise rather than a default time of the month over the period of record. The results corrected:

- Occasional instances when the first and second cruises were split by the 15th of the month (e.g., July 1990 first cruise of the month started before July 15th and lasted until July 18),
- Cases where the 2nd cruise of the month carried-over into the next month (e.g., July 1990 second cruise lasted until Aug 1), and
- Alignment of additional sampling results from shallow-water monitoring programs in recent decades that occurred on different dates than the CBP sampling cruises.

These corrections made the analysis more consistent with the sampling methodology for measuring bay-wide attainment. The updates resulted in some revisions to the historical time series for the indicator assessment of attainment. The largest change was an increase in Open Water (OW) attainment around 1990. This improvement in bay condition scoring was due to corrected cruise date groupings in July 1990 that had produced a poor representation of the pycnocline, and improper assignment of very low deep water dissolved oxygen concentrations into the Open Water designated use. Other slight changes in the OW, Deep Water (DW), and Deep Channel (DC) time series were identified after correcting these cruise dates or including additional sampling from shallow water programs. In all cases, the time series results are now more consistent for each segment and designated use.