Chesapeake Bay Program | Indicator Analysis and Methods (A&M) Document
Water Quality Standards Attainment Indicator

Each Indicator update must include an Analysis and Methods document that explains how the data are collected, analyzed, interpreted, and communicated to ensure transparency and consistency. Outcome Representatives and subject-matter experts complete the document during an Indicator's first iteration—addressing analytical methods, trends, and data quality—and update it with each new data release. The document is posted on ChesapeakeProgress with the associated data file, which contains more detailed metadata and reported metrics, for internal and external audiences across the Chesapeake Bay Program.

Relevant *Chesapeake Bay Watershed Agreement* Outcome(s): Water Quality, Standards Attainment and Monitoring (WQSAM)

Relevant Outcome Target(s):

- Maintain full core monitoring network operations (i.e., nontidal water quality, SAV, tidal water quality, benthic and community science) annually to support analysis and communication of water quality loads, trends and criteria attainment.
- Maintain or exceed the rate of improvement in the water quality standards attainment indicator relative to the 1985-2022 baseline.

Link to Management Strategy: The Management Strategy will be developed by Summer 2027.

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

A. **Analysis and Methods Document Metadata**
   Additional supporting metadata for this document is available in the associated Indicator data file; this document and the data file should be updated together to remain consistent.
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   2. **Resource Date:** April 30, 2026

B. **Analysis and Interpretation**
   Where appropriate, please provide references or location(s) of documentation (e.g., link to downloadable dataset, story map, tool, report).

   1. Briefly describe the dataset. What parameters are directly measured? What parameters are derived through calculation? For what purpose(s) are the data used? 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).

The attainment indicator presently uses a subset of the data otherwise necessary for a complete regulatory accounting of criteria evaluations underpinning water quality standards attainment assessments of tidal water Chesapeake Bay dissolved oxygen, water clarity and chlorophyll *a* (Figure 2). Criteria evaluation where data gaps exist is informed by science-based data relationships to estimate their attainment. The indicator, therefore, is recognized as an estimate of true attainment of these water quality standards.

Parameter data are derived as follows:

- Salinity (unitless) is directly measured with a probe.
- Water Temperature (T in ^oC) is directly measured with a probe.
- Dissolved oxygen (mg O_2/L) is directly measured with an optical probe unless otherwise described by the data source.
- Secchi depth (meters) is directly measured with a Secchi disc.
- K_d (1/m) measurements are made with a Licor sensor.
- Turbidity is measured as NTUs with a probe.
- Chlorophyll *a* (µg/L) is measured in two ways: 1) discrete, fixed station-based water samples collected and laboratory analysis of chlorophyll *a* and 2) 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.
- SAV acreage is calculated from aggregations of aerial photo-interpreted SAV area data to segment, zone and bay-wide levels.

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). Water clarity is assessed as light through the water, measured as K_d. K_d values are collected at fixed locations coincident with turbidity, salinity and chlorophyll *a*. Turbidity, salinity and chlorophyll *a* are recorded using DATAFLOW measures. K_d regressions are created from the fixed site location data and used to map light in the shallow waters of a segment.

2. What methods are used to collect, process, model, analyze, and/or transform raw data into the Indicator? Please cite methods, analytical tools, modeling programs, and relevant documentation. The published dissolved oxygen, chlorophyll a, and water clarity criteria assessment methodology currently used for assessing Chesapeake Bay water quality criteria attainment are described in *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*. Dissolved oxygen criteria assessment 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. Water clarity acres are calculated from the most recent consecutive three-year period of available shallow-water monitoring water clarity data. ArcGIS geodatabase in a Universal Transverse Mercator (UTM) Zone 18 projection was used to calculate area in square meters for all SAV beds.

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 can fully assess attainment across all segments, uses, and criteria. See Indicator Data file for assessment determination rules.

Impairment determinations were 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.

3. Are there established targets, thresholds, reference conditions, or desired-state values for this Indicator? If yes, describe them and how they were derived. The water quality standards describe the goals for designated uses applicable for a given 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. In addition, the target annual rate of improvement in the water quality standards attainment indicator is 0.2% per year, based on the indicator's 1985–2022 baseline rate of improvement (i.e., 0.2%). 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.

   The indicator does not include a full accounting of the year for all temporal resolutions necessary for measurements to evaluate 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 in attainment (e.g., pH, bacteria, temperature, toxics, etc).

4. Have there been any changes to targets, thresholds, data sources, methodology, or analytical approaches since the last reporting period? If yes, describe what changed and why. The framework of the assessment 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. In addition, one segment-specific update was made to the 2018-2020 assessment period to exclude the segment ELIPH from the assessment of deep water and deep channel dissolved oxygen criteria to address a discrepancy between the USEPA technical documentation for segmentation and criterion assessment and the Chesapeake Bay TMDL documentation. Moreover, the SAV acreage goal of the Back River (BACOH) has been corrected.

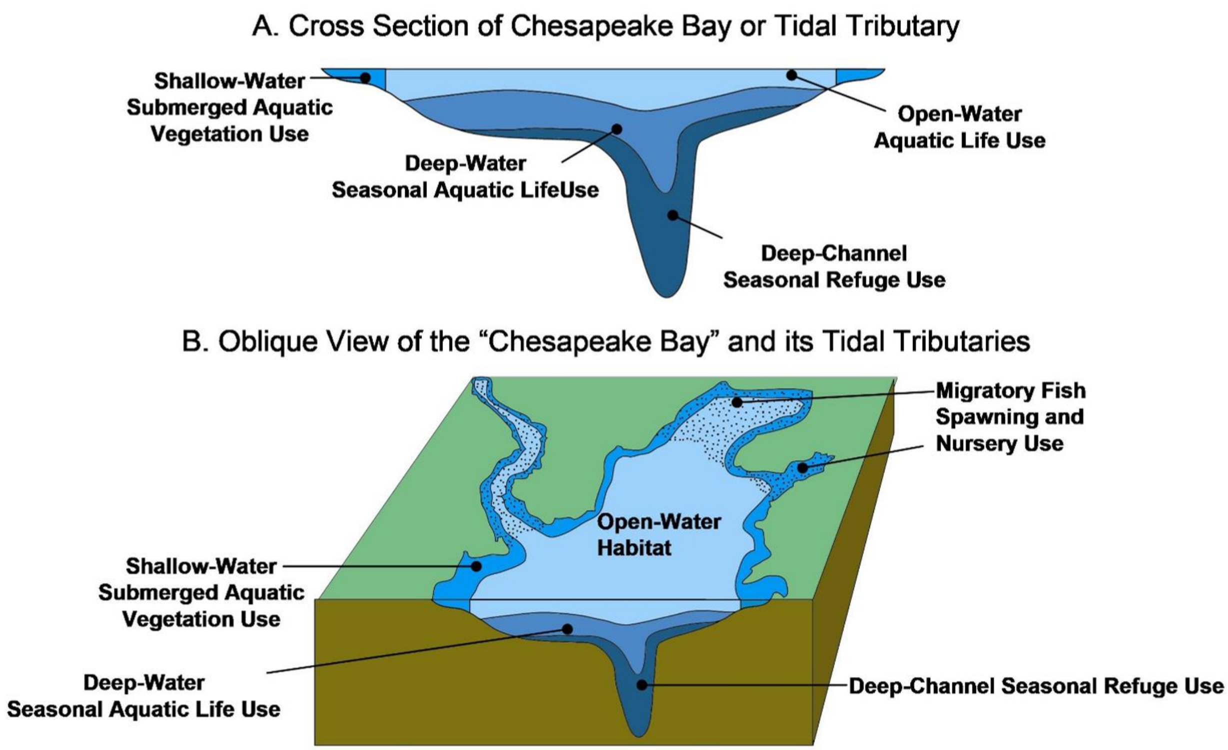
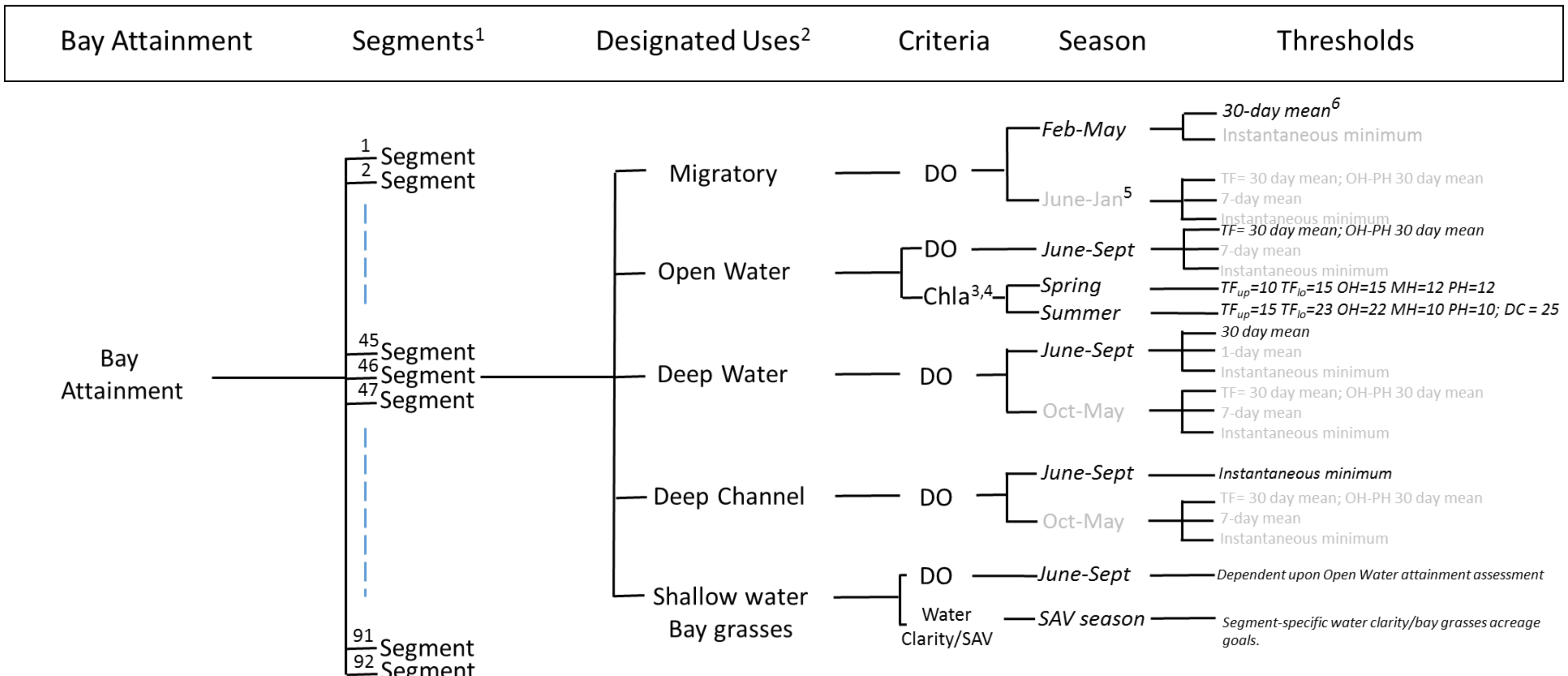


Figure 1. The five designated uses that apply to the Multimetric Water Quality Standards Attainment Indicator analysis.



1. There are 92 Chesapeake Bay segments (USEPA 2008)
2. Designated uses are segment specific. Not all designated uses apply to each Chesapeake Bay segment.
3. Salinity zone-specific thresholds on the James River, VA: TF_{up}=Tidal Fresh upper segment, TF_{lo}=Tidal Fresh lower segment, OH=Oligohaline, MH=Mesohaline, PH=Polyhaline. DC= Washington District of Columbia.
4. The James River chlorophyll *a* criteria are assessed for attainment of a geometric mean measure of the water quality.
5. Gray text are elements of the full water quality standards attainment not included in the indicator calculations.
6. USEPA (2003) does not have a 30-day mean Feb-May DO threshold. The decision for the indicator used a 30-day mean of 6 mg/l as Feb-May DO threshold, same as the 7-day mean.

Figure 2. The Multimetric Water Quality Standards Attainment Indicator assessment is a stripped-down version of the complete water quality standards attainment assessment. **Gray text** documents standards that exist but are not measured or reported on and to-date, excluded from the indicator calculations. Source: Hernandez-Cordero et al. (2020).

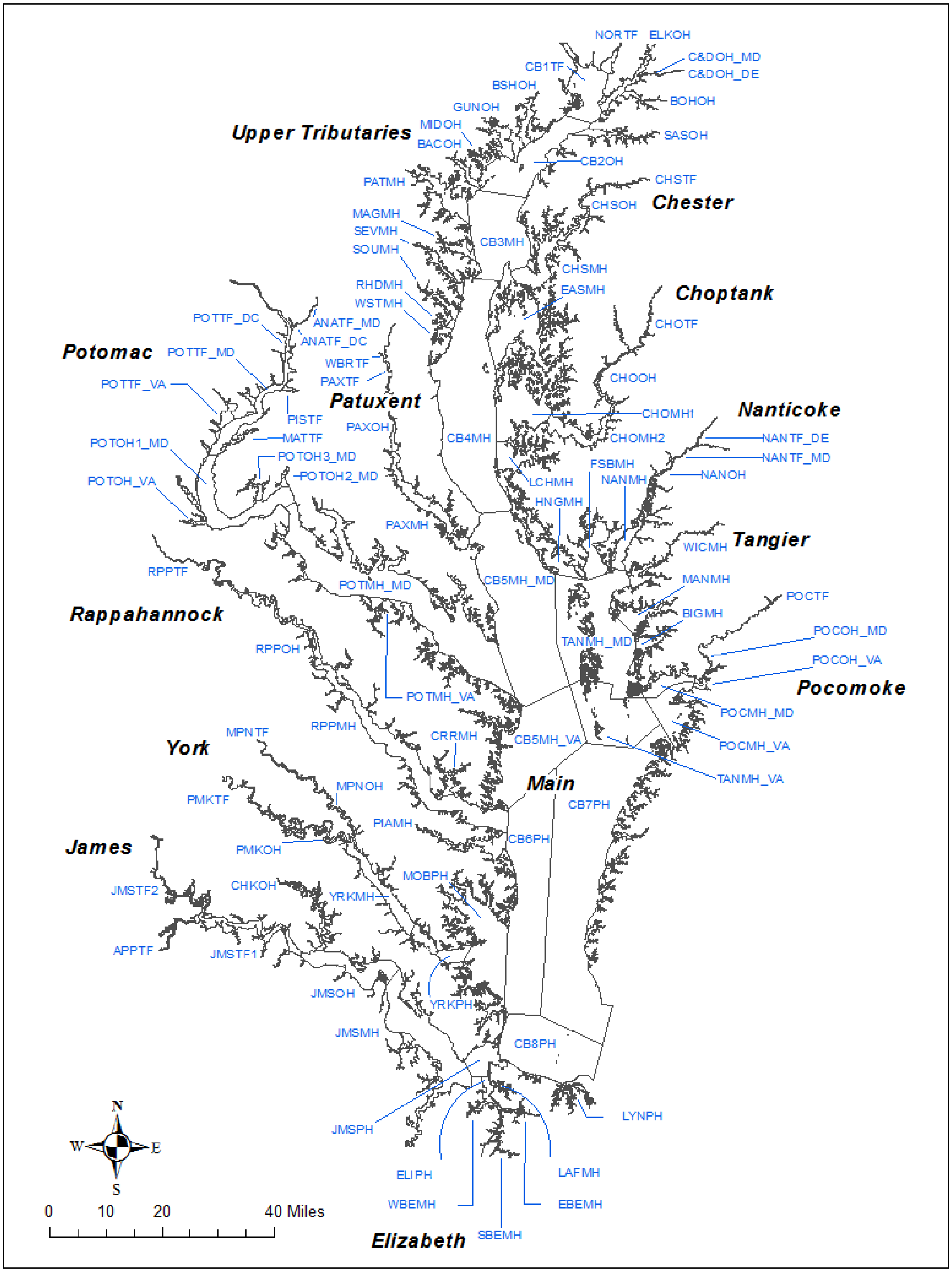


Figure 3. A map of the 92 Chesapeake Bay segments assessed for attainment status in the Multimetric WQS Attainment Indicator analysis.

C. Communicating the Data

Where appropriate, please provide references or location(s) of documentation (e.g., link to downloadable dataset, story map, tool, report).

1. Define the Outlook[1] toward achieving the Outcome as On Course, Off Course, Uncertain, or Completed. On Course. The water quality standards attainment score did not decline significantly since the last reporting period. The partnership continues to operate 150+ tidal monitoring stations; conduct annual analyses and reporting of attainment and long-term trends; complete a monitoring review to identify resource needs; and secure updated grants/interagency agreements and increased funding to sustain and expand networks (e.g., offshore vertical DO arrays) and participatory/community science, ensuring the data needed to track progress toward clean water across the Bay and its watershed.

2. What do the most recent data show compared to the previous reporting period? Are there any short-term trends? In the 2022-2024 assessment period, the estimated attainment showed a small decline (-0.4%) compared with the 2021-2023 assessment period. A major increase (10.2%) in the estimated attainment occurred with the deep water dissolved oxygen in 2022-2024, while a moderate increase (1.9%) in the estimated attainment occurred with the deep channel dissolved oxygen in 2022-2024. In contrast, a major decline (-5.1%) in the estimated attainment occurred with the open water dissolved oxygen in 2022-2024, and moderate declines (~ 2%) in the estimated attainment occurred with the migratory spawning and fish nursery dissolved oxygen and shallow water SAV/water clarity. No change was observed in estimated attainment for chlorophyll *a.*

3. What is the long-term trend since data collection began? Bay-wide water quality standards attainment has remained below the 100% goal and currently stands at 29.0% for 2022–2024. Since monitoring began, scores have fluctuated within a narrow range (26.1–42.2%), with periods of improvement and decline that align with major climatic events: an early multi-year improvement culminating in a peak during the 1999–2002 drought; a decline following Hurricane Isabel in 2003; lingering low values through 2011–2013 due to the rolling three-year assessment capturing the impacts of Hurricane Irene and Tropical Storm Lee (2011); a rebound to a record high in 2015–2017 as SAV acreage and dissolved oxygen conditions improved; and a subsequent decline tied to unusually wet conditions in 2018–2019, reflected in lower attainment between the 2016–2018 and 2019–2021 periods.

   Over the long term, the indicator shows a positive but modest rate of improvement that is still below the 0.2% per year target. Over the full record (1985–1987 to 2022–2024), the long-term slope is +0.15% per year and not statistically significant ($p = 0.248$), a result influenced by interannual variability in riverine inputs and the indicator's binary design, which is less sensitive to incremental change than continuous metrics such as attainment deficit. Even so, prior work documented a statistically significant improvement of about +0.33% per year from 1985–1997 to 2014–2016, with gains linked to total nitrogen reductions (Zhang et al., 2018 [https://doi.org/10.1016/j.scitotenv.2018.05.025]). Patterns also vary by designated use: a Mann–Kendall analysis for 1985–2024 (see Zhang et al., 2018 for methodology) found significant long-term improvements in deep water dissolved oxygen and shallow water bay grasses/water clarity. Complementary analyses using the non-binary attainment deficit metric show widespread, statistically significant dissolved oxygen improvements in open water, deep water, and deep channel across all salinity zones (tidal fresh, oligohaline, mesohaline, polyhaline). Together with recent interpretations (Zhang et al., 2024, 2025), these findings indicate increasing ecosystem resilience associated with sustained nutrient management, despite ongoing pressures from population growth and changing environmental conditions.

4. What is the key story told by this Indicator? Explain the "why" behind the data in clear, plain language. (e.g., Are there specific geographic areas of concern? Are there broader factors influencing the results?) The water quality data are used for meeting Clean Water Act 303d impairment listing requirements, tracking and accountability towards assessing progress in Chesapeake Bay restoration as it relates to meeting outcomes of the *Chesapeake Bay Watershed Agreement*, research support, water quality modeling calibration, and verification datasets that support the Chesapeake Bay TMDL. This Indicator estimates the percentage of Chesapeake Bay tidal waters that meet the water quality standards necessary to protect living resources survival, growth, and reproduction and determine the effectiveness of our management actions.
    i. What management actions or strategies have most influenced trends in the data? N/A
    ii. Are there any projects or case studies that showcase successful examples of progress? Provide contact information for individual projects or case studies, if possible. N/A
    iii. What obstacles or challenges (e.g., resources, capacity, funding) currently limit progress? Progress toward water quality standards attainment is limited by funding constraints that slow implementation of best management practices (e.g., shoreline management, wetland protection and health, and nutrient management); physical system changes such as reduced sediment storage at lower Susquehanna River dams (e.g., Conowingo), which increase nutrient and sediment delivery; and aging wastewater and stormwater infrastructure that is stressed by heavier precipitation. Additional pressures from population growth and a warming climate alter nutrient loads, water temperature, and dissolved

oxygen conditions. Ecological challenges—including invasive species (e.g., blue catfish), toxic contaminants, altered trophic structure, and depleted filter-feeder and submerged aquatic vegetation (SAV) populations—reduce the Bay's natural nutrient processing capacity. Habitat and shoreline issues, such as inadequate wetland maintenance/restoration, limited riparian buffers that filter and cool streams, and shoreline hardening, further constrain progress. Finally, significant monitoring and knowledge gaps (e.g., tracking wetland condition and change; understanding BMP effectiveness and lifespan; monitoring invasive-species impacts and broader trophic dynamics) and the need to better align societal behaviors and stewardship with water-quality goals continue to impede advancement.

D. Data Quality

Where appropriate, please provide references or location(s) of documentation (e.g., link to downloadable dataset, story map, tool, report). For more information on metadata standards, see Chesapeake Bay Program Metadata Specification document.

1. Were the data collected and processed under an EPA-approved Quality Assurance Project Plan (QAPP)? Yes, methods are described in the Quality Assurance Project Plan (QAPP) on file for the EPA CBPO nontidal water quality monitoring. Documentation is available at https://www.chesapeakebay.net/what/programs/quality-assurance. Each data provider has quality assurance protocols that they implement to ensure that high quality data are available for analysis. For more details, refer to Section B.2.

2. Were sampling and analytical procedures consistent throughout the data record? Note any deviations, transitions, or merging of datasets that may affect interpretation. 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, to allow for episodic occurrence of deep-water and deep-channel designated uses. Revisions to the water clarity acres assessment methodology were implemented in 2008. These refinements are published in *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*.

   Note: Individual states hold the legal authority under Clean Water Act Sections 303(d) and 305(b) to issue official water quality assessments and impairment listings in their even-numbered year Integrated Reports. The Partnership's water quality indicator provides a Bay-wide estimate of overall progress using shared monitoring data, but it does not replace official state regulatory assessments. A formal complete assessment of all dissolved oxygen criteria to evaluate the attainment of standards is not available currently. Please click here for Maryland's Integrated Report. Please click here for Virginia's Integrated Report.

E. Additional Information (Optional)

Where appropriate, please provide references or location(s) of documentation (e.g., link to downloadable dataset, story map, tool, report).

1. Is there any additional information that would help ensure accurate communication and prevent misinterpretation of this Indicator? Include additional descriptions of analysis and methods, relevant context, caveats, or links to work plans or research, if applicable. In the 2018–2020 assessment, segment ELIPH was excluded from deep-water and deep-channel dissolved oxygen criteria due to a discrepancy between USEPA technical documentation (followed by Virginia regulations) and the Chesapeake Bay TMDL, with the former designating ELIPH as open water only. Because no changes have been published adding DO-related designated uses for ELIPH, the complete time series and analyses were revised to correct this historical methodological error.

   The indicator now applies water clarity acreage data to all applicable years by using a rolling three-year series (e.g., 2008–2010, 2009–2011, 2010–2012), rather than the states' sequential, non-overlapping three-year 303(d) assessment blocks (e.g., 2008–2010, 2011–2013). Because underlying data are collected annually and the water quality standards "best-of-three-years" decision rules allow a segment to meet its goal via SAV acreage or water clarity acres, monitoring can shift once a segment meets in year 1 or 2, leaving only 1–2 years of water clarity data in a given three-year window. In the 303(d) framework that single year affects one block, but in the indicator's rolling series it influences three consecutive windows.

   For dissolved oxygen–designated uses, the assessment method is unchanged, but cruise dates were corrected by assigning samples to their actual cruises rather than splitting by a mid-month rule, which had created interpolation gaps affecting pycnocline definitions and spatial attainment. These fixes—addressing cruises spanning the 15th, carryovers into the next month, and alignment with shallow-water programs—revised parts of the historical time series, most notably increasing Open Water attainment around 1990 by correcting a July 1990 misgrouping that misrepresented the pycnocline and misassigned very low deep-water DO to Open Water; smaller adjustments occurred in Open Water, Deep Water, and Deep Channel, yielding more consistent results by segment and designated use.

Additional Citations, Data Resources and Contact Information:

- Salinity, water temperature, DO, Secchi depth, Kd, turbidity, 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* criteria assessments are conducted at CBPO by Richard Tian (UMCES-CBPO). Water clarity/SAV criteria assessments are conducted by the Maryland Department of Natural Resources (Mark Trice), Virginia Institute of Marine Science (Dave Parrish), and Virginia DEQ (Tish Robertson).
- DO, Secchi depth, K_d, turbidity, 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).
- SAV area data can be downloaded from http://web.vims.edu/bio/sav/StateSegmentAreaTable.htm.

References:

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[1]*Outlook:* Outlook is the forecasted trajectory for whether the Chesapeake Bay Program is on course to achieve the Outcome. An Outcome's Outlook may be On Course, Off Course, Uncertain, or Completed.