4-Dimensional Interpolator FAQs

The Chesapeake Bay restoration effort is guided by science-based water quality standards and the Chesapeake Bay Program (CBP) partnership's Watershed Agreement, which together drive annual investments across the watershed. Despite significant efforts and commitments, current tools and monitoring are not sufficient to fully evaluate whether applicable water quality standards in the Bay are being attained. To address this challenge, the CBP Partnership is advancing the development of a four-dimensional (4D) interpolation tool. This document provides quick answers to common questions and enhances stakeholder understanding of the tool.

DRAFT: We plan to expand on answers and add additional questions! We are looking for feedback on questions to add.

What is 4D?

4D is space (3D) plus time. It considers space and time simultaneously.

Why does the CBP need a new method for water quality assessment?

The CBP currently uses a 3D interpolator tool developed in 2006 to estimate water quality concentrations across the Chesapeake Bay and its tidal tributaries using observations taken at specific locations. The 3D interpolator was not designed to interpolate through time or work effectively with unstructured data having mixed time scales and sampling patterns and sourced from multiple monitoring programs. Through monitoring investments over the twenty years along with advancements in technology, there is more high frequency data now to fill in temporal gaps, and the CBP needs an updated analysis tool to maximize this monitoring investment. CBP prioritized developing a new analytical tool to match the new available data rather than determining how to fit the new data types into the 3D tool that was not designed for it. The 4D interpolator will use data from all available monitoring sources, including high frequency, to fill in gaps between data based on observed patterns. Use of all data sources results in more accurate condition estimates which means more accurate determination of impairment and attainment for water quality standards.

How will the CBP utilize the 4D interpolator?

- Help answer how we are doing towards meeting our goals in the *Chesapeake Bay Watershed Agreement* (e.g. Water Quality Standards Attainment Indicator).
- Support Jurisdictions' reporting of 303(d) lists.

- One step in the analysis is designed to develop planning targets as part of the partnership suite of modeling tools. This is a commitment of the Watershed Agreement under the Reduce Excess Nutrients and Sediment Outcome. Integration in the planning targets will also lead to effective Watershed Implementation Plans.
- Research Applications internally and with CBP partners (academia and other).

What is the goal of a 4D Interpolator tool?

Spatial-and-temporal interpolation of water quality monitoring data collected in the tidal waters of the Chesapeake Bay, enabling the evaluation of both long- and short-duration water quality criteria.

The tool should:

- Interpolate observed dissolved oxygen in space and time ("4D") at every node in the interpolation grid to fill data gaps
    - Note: Focus on development so far has been on dissolved oxygen, but ultimately chlorophyll a and clarity may be evaluated as well
- Provide statistical estimates of uncertainty
- Reproduce daily and hourly variability of the data
- Allow for post-processing of the interpolation output into designated uses (DU)
- Allow for interpolation function to be different in time and space based on what the data tell us

Is the 4D Interpolator a process-based model?

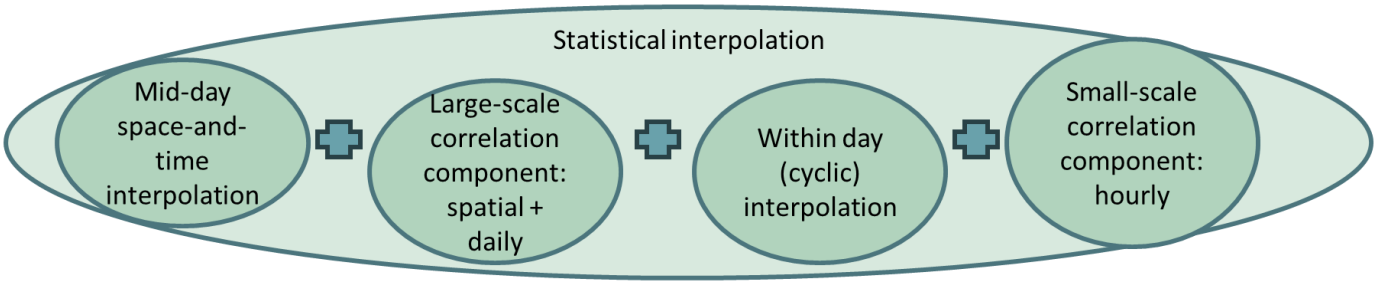
No. The 4D Interpolator is based on monitoring observations. The interpolator may occasionally be referred to as a "model," but it is an empirical model based on the relationships and patterns of observed data only, which is not the same as the process-based watershed and estuarine models used by the CBP partnership.

What data is being used in the 4D Interpolator?

The 4D interpolator uses data from various spatial and temporal scales including high frequency data which was not used in the 3D interpolator:

Fixed-station network	Cruise-track monitoring (DataFlow*)	Continuous monitoring (ConMon*)	Vertical arrays (NOAA)	Additional State Agency Collected Data	Community Monitoring (Tier 3)	Future Data Sets
✓ Fixed location; broad spatial coverage ✓ Long-term consistency ✓ Profiles (every 1-2 meter to bottom) ✓ 150+ sites ✓ 1-2x/month	✓ Surface mapping continuous data (~0.5 m) ✓ ≈ 8-10 sites/yr* ✓ ≈ 4-7 cruises per site (Apr-Oct) ✓ Sites commonly rotated about every 3 years to broaden coverage	✓ Fixed location ✓ High frequency sampling ✓ Fixed depth near surface or bottom ✓ ≈ 25-30 sites/yr*; typically, 6-9 months/yr; some year round ✓ Sites commonly rotated about every 3 years to broaden coverage	✓ Fixed location; multi-depth ✓ High frequency sampling ✓ New since 2022 ≈ 2-3 sites/yr ✓ ≈ 5-9 month deployments	✓ Expands monitoring breadth ✓ 1-2x/month	✓ Expands monitoring breadth ✓ 1-2x/month	✓ Building the framework of the tool to be ready and able to incorporate future data sets

What are the main components of the tool?



- *Mid-day space-and-time interpolation*: Produces daily (mid-day) Bay-wide DO estimates that capture the broad spatial pattern from day to day.
- *Within day (cyclic) interpolation*: Uses high-frequency monitoring to characterize diel and tidal DO cycles where data exist and propagates those cycles to nearby areas without high-frequency data to produce hourly DO estimates.
- *Large- and small-scale correlation components*: Estimated from monitoring data and used to represent the remaining structured variability not captured by the mid-day or cyclic terms—so results can vary realistically over long and short space/time scales and support multiple realizations/simulations that mimic observed high-frequency variability.

Why use simulations?

The components of the model will be run through multiple simulations to increase confidence in the results. It minimizes false positives and false negatives assessments.

What will the results show?

The multiple simulations will output DO interpolations based on the data every hour. The results consider both space and time simultaneously. The hourly DO results will help answer the frequency of violation over an assessment period for a segment. The results are the probability of failing the criteria at a segment. This will allow the CBP to assess criteria that were not assessed before. The Criteria Assessment Protocol Workgroup will decide what frequency is chosen for the different criteria.

The 4D interpolator will provide plots that show how close or far a segment is from meeting criteria along with diagnostics of when and where violations occur.

Why use GAMs?

Question about interpolator grid

Question about boundaries set (target segment and boundaries)

Why can't the data be used for assessment without interpolation?

What are the explanatory variables?