Chesapeake Bay Program | Indicator Analysis and Methods (A&M) Document

Nitrogen, Phosphorus, and Suspended Sediment Loads to the Bay

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.
- Analyze and report status/loads, trends and factors affecting those trends for nontidal and tidal water quality.

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? This Indicator quantifies annual loads of nitrogen, phosphorus, and suspended sediment delivered to the Chesapeake Bay, along with long-term trends, to support assessment of water quality conditions and management effectiveness.

- River discharge, total nitrogen, total phosphorus, and suspended sediment concentrations are measured directly from the River Input Monitoring (RIM) sites.
- Wastewater discharges and nutrients are reported to EPA from the seven Bay watershed jurisdictions.
- RIM load estimates are made by USGS using the Weighted Regressions on Time, Discharge, and Season - Kalman Filter (WRTDS-K) model (Hirsch et al., 2010; Lee et al., 2019; Zhang and Hirsch, 2019).
- Wastewater loads (i.e., those delivered to the Bay) are estimated from EPA discharge monitoring (end-of-pipe) adjusted by delivery factors used in the CBP Phase 6 Watershed Model.
- Load contributions from unmonitored areas (i.e., below RIM) are calculated by scaling observed river input loads using information from the Phase 6 Watershed Model.
- For nitrogen, atmospheric deposition to tidal waters is estimated using the CMAQ Model for dry deposition (Dennis et al., 2007 and Hameedi et al., 2007) and a regression model for wet deposition (Grimm and Lynch, 2000, 2005; Lynch and Grimm 2003).
- The flow-normalized trends are estimated by USGS using the Weighted Regressions on Time, Discharge, and Season (WRTDS) model (Hirsch et al., 2010) for the RIM stations and for the extended Nontidal Network stations.

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 methods for making these calculations have been reviewed internally at the Chesapeake Bay Program (the Nontidal Water Quality Workgroup). A scientific manuscript documenting the methods used to estimate fluvial loads has been published (Keller et al., 2011). Additionally, the WRTDS (Hirsch et al., 2010) and WRTDS-K (Zhang and Hirsch, 2019) approaches are both formally documented in scientific journal publications. River monitoring data have been collected according to approved field and laboratory methods and associated quality control protocols that are described by Chesapeake Bay Program (2017). CBP's documentation of the Phase 6 Watershed Model can be found here: https://cast.chesapeakebay.net/Documentation/ModelDocumentation. Beginning in 2012, RIM site loads are determined using an improved statistical technique called the WRTDS model (Weighted Regressions on Time, Discharge, and Season). For details, please refer to Hirsch et al. (2010). This allows for enhanced statistical analysis of data. A comparison of the WRTDS model to the previously used ESTIMATOR model is available -- see Moyer et al. (2012). Beginning in 2020, the WRTDS-K model is used to estimate the RIM loads. This approach can provide generally more accurate estimates of loads than the

standard WRTDS model by accounting for the autocorrelation structure of model residuals (Lee et al., 2019; Zhang and Hirsch, 2019).

In addition, the flow-normalization (FN) procedure of WRTDS (Hirsch et al., 2010) is used to compute the long-term and 10-year trends for total nitrogen, total phosphorus, and suspended sediment loads at the RIM stations and at the extended Nontidal Network stations. These FN trends remove the year-to-year variability in river flow; by doing so, changes in nitrogen, phosphorus, and suspended-sediment loads resulting from changing sources, delays associated with storage and transport of historical inputs, and (or) implemented management actions are identified.

Atmospheric deposition (nitrogen only) is estimated using the CMAQ Model for dry deposition (Dennis et al., 2007 and Hameedi et al., 2007) and a regression model for wet deposition (Grimm and Lynch, 2000, 2005; Lynch and Grimm 2003).

Finally, the total load inputs to the Bay have been analyzed using the Mann-Kendall test and Sen's slope approaches to compute long-term trends. The Mann-Kendall test is a nonparametric approach for detecting monotonic trends (Kendall, 1975), while the Sen's slope approach quantifies the trend magnitudes (Sen, 1968).

3. Are there established targets, thresholds, reference conditions, or desired-state values for this Indicator? If yes, describe them and how they were derived. This indicator does not have an established target, but it is developed in the context of the Chesapeake Bay Total Maximum Daily Loads (TMDLs), which establish nutrient load reduction goals that will eventually result in the achievement of water quality standards in the Bay for dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll *a*.

   The Chesapeake Bay TMDL issued in 2010 set Bay watershed limits of 185.9 million pounds of nitrogen (with an additional allocation of 15.7 to tidal waters from atmospheric deposition, for a total limit of 201.63 million pounds), 12.5 million pounds of phosphorus, and 6.45 billion pounds of sediment per year. These load targets are based on modeled scenarios that result in the Chesapeake Bay and its tidal tributaries meeting their water quality criteria for dissolved oxygen, water clarity/SAV, and chlorophyll *a*.

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. No change since the last reporting period. See Section E for details on historical changes in methodology.

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 partnership continues to operate 150+ tidal monitoring stations; conduct annual analyses and reporting of attainment, load reductions, 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? During 2024, the average river flow to the Bay was 54.3 billion gallons per day, representing a 28% increase over 2023. Correspondingly, pollutant loads entering the Bay increased substantially, with total nitrogen, total phosphorus, and suspended sediment loads rising by approximately 88 million pounds, 9.1 million pounds, and 5.5 billion pounds, respectively. These changes represent increases of 44% for nitrogen, 94% for phosphorus, and 46% for suspended sediment, indicating degrading conditions in 2024 relative to 2023, as reflected by the higher pollutant loads delivered to the Bay.

   Total Nitrogen: Approximately 287 million pounds of total nitrogen reached the Bay during the 2024 water year (WY).

   Total Phosphorus: Approximately 18.8 million pounds of total phosphorus reached the Bay during the 2024 water year (WY).

   Suspended Sediment: Approximately 17.5 billion pounds of suspended sediment reached the Bay during the 2024 water year (WY)

3. What is the long-term trend since data collection began? Overall, loads of total nitrogen, total phosphorus, and suspended sediment are trending in the right direction over the long-term period. The total nitrogen trend is statistically significant, whereas the total phosphorus and suspended sediment trends are not statistically significant, largely due to inter-annual variability in river flow.

   Compared with the long-term (1985-2024) average conditions, river flow is 4% higher in 2024, and loads of total nitrogen, total phosphorus, and suspended sediment are 14%, 4%, and 8% lower in 2024, respectively. These results indicate lower loads of nutrients and sediment on a per unit flow basis, suggesting effects of other factors (including management actions) on controlling nonpoint sources in the Bay watershed. This indicates improving conditions (i.e., decreases in loads) over the long term.

Nitrogen: Estimated nitrogen loads showed an overall decline of -1,300 tons/yr in the period between 1985 and 2024, which is statistically significant ($p < 0.05$). This reduction reflects a combination of reductions in below-RIM loads (-840 tons/yr; $p < 0.01$) and RIM loads (-440 tons/yr; $p = 0.29$). In addition, the below-RIM reduction is driven by below-RIM point sources (-680 tons/yr, $p < 0.01$), and to a lesser extent, by atmospheric deposition to the tidal waters (-85 tons/yr, $p < 0.01$). The significant below-RIM point source reductions in total nitrogen (TN) are a result of substantial efforts to reduce nitrogen loads from wastewater treatment facilities by implementing advanced treatment technologies. The significant decline in atmospheric deposition of TN to the tidal waters is consistent with findings that atmospheric deposition of nitrogen has decreased due to benefits from the Clean Air Act implementation.

Phosphorus: Estimated phosphorus loads showed an overall decline of -44 tons/yr in the period between 1985 and 2024, although it is not statistically significant ($p = 0.33$). This reduction reflects a combination of reductions in below-RIM loads (-32 tons/yr) and RIM loads (-9 tons/yr), although only the former is statistically significant ($p < 0.05$). Within the below-RIM load, point sources showed a statistically significant decline in this period (-34 tons/yr; $p < 0.01$), whereas nonpoint sources showed a long-term increase (12 tons/yr; $p = 0.33$). This total phosphorous (TP) point source load reduction has also been attributed to significant efforts to reduce phosphorus in wastewater discharge through the phosphorus detergent ban in the early part of this record, as well as technology upgrades at wastewater treatment facilities.

Sediment: Estimated suspended sediment loads showed an overall decline of -18,000 tons/yr in the period between 1985 and 2024, although it is not statistically significant ($p = 0.65$). This reduction reflects a combination of reductions in RIM loads (-14,000 tons/yr) and below-RIM loads (-4,600 tons/yr), although neither is statistically significant. Within the below-RIM load, point sources of sediment showed a statistically significant decline in this period (-490 tons/yr; $p < 0.01$), whereas nonpoint sources showed a non-significant decline (-4,000 tons/yr; $p = 0.55$).

For trend information for the River Input Monitoring stations, refer to the latest USGS trend data release.

For trend information for the Nontidal Network stations, refer to the latest USGS trend data release and associated geo-narratives.

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?) Year-to-year pollution loads to the Chesapeake Bay are driven largely by hydrology, with management and land use practices superimposed on that variability. By tracking annual river flow alongside total nitrogen, total phosphorus, and suspended sediment loads since 1985, the Indicator shows that wet winters and springs deliver more runoff pollution that shapes summer water quality, while dry years reduce loads. These precipitation-driven swings don't necessarily signal improvement or decline in watershed health on their own, and some nutrients move slowly through groundwater, creating lags between management actions and observed changes. The Indicator provides essential context to distinguish weather-driven variability from longer-term trends attributable to land use and management.
    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 is constrained by aging wastewater and stormwater infrastructure that is increasingly stressed by heavier precipitation, along with diminished sediment storage at the Conowingo Dam (near maximum infill) that increases nutrient delivery to the estuary. Population growth and warming temperatures compound pressures on nutrient loads, water temperature, and dissolved oxygen conditions, while shoreline hardening and insufficient protection and restoration of wetlands and riparian buffers reduce natural filtering, cooling, and retention capacity. Additionally, many jurisdictions lack the financial, technical, and regulatory resources to oversee and implement MS4 and other stormwater programs, deliver priority conservation practices in priority watersheds, and maintain robust BMP tracking, verification, and reporting. Current management and accounting frameworks underrepresent beneficial ecological services and nitrogen reductions from acid mine drainage (AMD) restoration, anaerobic processing in wetlands and restored floodplains, and nutrient assimilation by freshwater mussels, limiting the ability to credit and scale effective actions.

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. Yes.

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. Loads that were estimated for the Below-RIM site areas (nonpoint source loads and atmospheric deposition to tidal waters) should be regarded as modeled. Although these data are calculated using monitoring and modeling derived data, the values represent essentially modeled loads. While this approach is very powerful it is imperative to clearly label these data as estimated (modeled). This is the main justification for using the stacked bar in the indicator plots.

   (Note: Survey for river flow portion of indicator is available at http://www.chesapeakebay.net/indicators/indicator/river_flow_into_chesapeake_bay.)

   Methodology Changes Over Time:
   One major change in methodology occurred in the 2023 assessment period: CAST-2023 was used to replace CAST-2019 as the data source for below-RIM loads. For more information on CAST, see https://cast.chesapeakebay.net/About.

   A major change in methodology occurred in the 2020 assessment period. Nutrient and sediment loads were previously determined by applying the WRTDS (Weighted Regression on Time, Discharge, and Season) method (Hirsch et al., 2010). Recently, a modified version called WRTDS-Kalman Filter (WRTDS-K) was developed, which can provide generally more accurate estimates of loads than the standard WRTDS model by accounting for the autocorrelation structure of model residuals (Lee et al., 2019; Zhang and Hirsch, 2019). In this assessment, total nitrogen, total phosphorus, and suspended sediment loads from the RIM watersheds were estimated using WRTDS-K for the entire period.

Several major changes in methodology occurred in the 2019 assessment period. First, the starting year of the reported loads was extended back from 1990 to 1985, because loads from all relevant sources have been made available for water years starting with 1985. Second, below-RIM loads are also assessed and reported for suspended sediment to be consistent with the reporting of total nitrogen and total phosphorus loads. Third, CAST-2019 was used to replace CAST-2017 as the data source for below-RIM loads. Fourth, flow adjustments are now only applied to the non-shoreline part of the below-RIM nonpoint source loads for total nitrogen, total phosphorus, and suspended sediment.

For consistency purposes, all flows and loads since 1985 have been computed using the Phase 6 Watershed Model. Comparisons between Phase 6 and Phase 5.3.2 showed (1) negligible changes in tidal (i.e., below-fall-line) wastewater inputs (for both N and P), (2) negligible changes in atmospheric deposition to tidal (i.e., below-fall-line) waters (for N), (3) moderate increases in tidal (i.e., below-fall-line) nonpoint source inputs (for N), and (4) large increases in tidal (i.e., below-fall-line) nonpoint source inputs (for P). The latter increase was partially due to the inclusion of shoreline erosion in the Phase 6 model. For sediment, no change was observed because only river input loads were assessed.

For detailed descriptions of differences between Phase 5 and Phase 6 versions of the Chesapeake Bay Watershed Model and advances with the latter tool, see the model documentation through the CAST website at https://cast.chesapeakebay.net/Documentation/ModelDocumentation.

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.