Chesapeake Bay Program | Indicator Analysis and Methods Document

Nitrogen, Phosphorus, and Suspended Sediment Loads to the Bay

Updated April 2021

Indicator Title: Nitrogen, Phosphorus, and Suspended Sediment Loads to the Bay

Relevant Outcome(s): 2017 and 2025 Watershed Implementation Plans (WIP) Outcome

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?

River discharge, nitrogen, phosphorus and suspended sediment concentrations are measured directly at the river input monitoring (RIM) sites. Wastewater discharges and nutrients are reported to EPA from the seven Bay watershed jurisdictions. Total delivered suspended sediment loads are estimated using only RIM monitoring data.

RIM load estimates are made by USGS using the Weighted Regressions on Time, Discharge, and Season (WRTDS) model (Moyer and Blomquist, 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 details of the Phase 6 Watershed Model, please see https://cast.chesapeakebay.net/Documentation/ModelDocumentation. For nitrogen, atmospheric deposition to tidal waters was estimated with the CMAQ Model for dry deposition (Dennis et al. 2007 and Hameedi et al. 2007) and a regression model developed by Grimm and Lynch (2000, 2005; Lynch and Grimm 2003) for wet deposition. These data are collected for long-term monitoring purposes.

(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: USGS, EPA, CBPO.
- Custodians:
  - River input data – Doug Moyer (USGS, 804-261-2634).
  - Wastewater and nonpoint source estimates delivered to the Bay from portions of the watershed downstream from RIM sites – Gary Shenk (USEPA-CBPO, 410-267-5745).
  - Nitrogen loads from atmospheric deposition to tidal waters – Lewis Linker (US EPA-CBPO, 410-267-5741).
- Chesapeake Bay Program Contact (name, email address, phone number):
  - Scott Phillips (USGS, swphilli@usgs.gov, 410-295-1353).

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

Data set and associated dictionaries and definitions are available from the custodians of the source data listed in question 2.

B. Temporal Considerations

(4) Data collection date(s):

Water year (October 1-September 30) 1985-2019.

(5) Planned update frequency (e.g., annual, biannual, etc.):
- Source Data: River input data, watershed model scenario runs, wastewater loads, and atmospheric deposition to tidal waters (nitrogen only) are all updated annually.
- Indicator: Annual.

(6) Date (month and year) next data set is expected to be available for reporting:

Data are typically analyzed by the USGS for river input monitoring program by July of each year. Atmospheric deposition is available by March each year.

C. Spatial Considerations

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

Entire Chesapeake Bay watershed.

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

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

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

Data for river input monitoring and wastewater are spatially explicit; however, these data are combined to make a watershed-wide estimate of loads from unmonitored areas in the below-RIM areas (i.e., tidal nonpoint sources).

D. Communicating the Data

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

Decrease nutrient and sediment loads to levels that will result in the achievement of water quality standards in the Bay for dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll *a*.

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

For load targets of this indicator, see question 25. The current status of this indicator is described as follows.

Flow: Annual average river flow to the Bay during the 2019 water year (WY) was 84.5 billion gallons per day (BGD), which is 60% higher than the 1985-2019 mean flow of 52.8 BGD. The 2019 WY flow is 14.0 BGD more than the 2018 WY flow.

Nitrogen: Approximately 491 million pounds of nitrogen reached the Bay during the 2019 water year (WY), which is 40% higher than the 1985-2019 mean load of 351 million pounds. The 2019 WY load is 71 million pounds more than the 2018 WY load.

Phosphorus: Approximately 34.8 million pounds of phosphorus reached the Bay during the 2019 water year (WY), which is 52% higher the 1985-2019 mean load of 22.9 million pounds. The 2019 WY load is 3.3 million pounds less than the 2018 WY load, although 2019 (WY) had a higher river flow than 2018 (WY).

Suspended sediment: Approximately 26.6 billion pounds of suspended sediment reached the Bay during the 2019 water year (WY), which is 25% higher than the 1985-2019 mean load of 21.2 billion pounds. The 2019 WY suspended sediment load is 2.2 billion pounds less than the 2018 WY load, although 2019 (WY) had a higher river flow than 2018 (WY).

(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?

Update occurred in the 2019 assessment:
Several major changes in methodology occurred in this 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 nitrogen and 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 nitrogen, phosphorus, and suspended sediment.

Update occurred in the 2018 assessment:

The Chesapeake Bay Program partnership upgraded its watershed model from Phase 5.3.2 to the Phase 6 Watershed Model to accommodate new science, additional years of monitoring data from the non-tidal and tidal monitoring networks, and many other updates to data and methods employed by the watershed and estuary (Water Quality and Sediment Transport) models.

For consistency purposes, all flows and 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 site at https://cast.chesapeakebay.net/Documentation/ModelDocumentation. The introductory "Overview" section is particularly helpful for a larger picture of how the Watershed Model has changed.

Update occurred in 2012:
Refer to "Additional Information" section at the end of this document. River input load estimates are calculated using WRTDS (Hirsch and others, 2010; Moyer and others, 2012; Chanat and others, 2016). This approach utilizes an extended period of streamflow and water-quality measurements to predict load based on the relation of concentration with time, discharge and season. The method utilizes all measurements but weights the values based on nearest values in the dimensions of time, discharge and season. As a result, reported load estimates may fluctuate with periodic updates to the data series. This fluctuation results from newly collected data being included in the analysis and improving the characterization of historical periods. Over time, the load estimates stabilize and will likely show variations of less than 1% with subsequent updates. See Hirsch et al. 2010, Moyer et al. 2012, and Chanat et al. 2016 for more information.

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

Since 1985, the first year where all necessary data were available, the amount of nutrients delivered to the Bay from the watershed has changed dramatically from year-to-year, complicating efforts to determine trends through time. In this regard, Mann-Kendall trends and Sen's slope estimates have been computed for each loading source and are included in the "Long-term Trend" tab of the data file.

Nitrogen: Estimated total nitrogen loads showed an overall decline of 1,062 tons/yr in the period between 1985 and 2019, although it is not statistically significant ($p = 0.28$). However, there were significant below-RIM point source reductions in the total nitrogen load, which are a result of substantial efforts to reduce nitrogen loads from wastewater treatment facilities by implementing advanced treatment technologies. There was also a significant decline in atmospheric deposition of TN to the tidal waters, which 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 9.0 tons/yr in the period between 1985 and 2019, although it is not statistically significant ($p = 0.86$). There was a significant TP point source load reduction, however, which 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.

Suspended sediment: Estimated suspended sediment loads showed an overall increase 8,619 tons/yr in the period between 1985 and 2019, although it is not statistically significant ($p = 0.86$). Both the RIM and below-RIM loads showed long-term increases, but both are not statistically significant. Within the below-RIM load, point sources showed a statistically significant decline in this period (-642 tons/yr; $p < 0.01$), whereas nonpoint sources showed a long-term increase (1,270 tons/yr; $p = 0.89$).

(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?

See the comparison of 2019 and 2018 loads and flow in question 12 of this document. Nitrogen load to the Bay is much higher than last year, mainly because river flow, which is based on precipitation, is higher than last year. Both river input from the RIM tributaries and below-RIM nonpoint sources contributed to the higher load in 2019. By contrast, phosphorus and suspended sediment loads are lower in 2019 than 2018, despite the increase in river flow. Decreases in both river input of phosphorus and sediment from the RIM tributaries and below-RIM nonpoint sources contributed to the lower load in 2019. This indicates lower loads of phosphorus and sediment on a per unit flow basis, suggesting effects of other factors, including management actions on controlling nonpoint sources in the Bay watershed (both in RIM and below-RIM areas).

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

Pollutant loads to the Chesapeake Bay in any given year are influenced by changes in land-use activities and management practices, as well as the amount of water flowing to the Bay (hydrology). This indicator tracks annual changes in river flow and the nitrogen, phosphorus and sediment loads delivered to the Bay each year, beginning in 1985, to help understand and explain trends in Bay water quality conditions.

Each day, billions of gallons of freshwater flow through thousands of miles of streams and rivers that eventually empty into the Bay. That water also carries polluted runoff from throughout the watershed.

The amount of water flowing into the Bay from its tributaries has a direct impact on how much pollution is in the estuary:

- Generally, as river flow increases, it brings more sediment and nutrient pollution to the Bay.

- Runoff from winter and spring rains delivers pollution loads that drive summer water quality conditions in the Bay.
- Years with low or high amounts of precipitation can result in changes to pollution levels in the Bay, but not mean the health of the watershed is improving or declining.

Not all rain water runs off the land. Some water seeps into the soil, carrying nutrients into groundwater. The travel time of nutrients through the watershed ranges from weeks to centuries. This can result in a lag time between implementing management actions and improvements in water quality.

Scientists use a combination of the following information to estimate the loads to the Bay:

- river flow discharge measurements;
- test results from water samples collected at river input monitoring (RIM) sites to estimate nitrogen, phosphorus and sediment concentrations that are converted into loads from the majority of the watershed;
- test results from water samples collected at wastewater treatment facilities downstream of the RIM sites to estimate nitrogen and phosphorus concentrations that are converted into loads;
- computer modeling to estimate nitrogen and phosphorus loads from nonpoint sources downstream of the RIM sites;
- atmospheric deposition of nitrogen delivered directly to the water surface of the bay and the waterways of the watershed that contributes to overall pollution levels experienced by the bay tidal waters.

The load assessment approach for this indicator differs from the approach used to estimate loads for the 2025 Watershed Implementation Plans (WIP) outcome. The WIP outcome estimates are computer-simulated nitrogen, phosphorus and sediment loads to the Bay derived from the composite effects of BMP implementation and changing conditions in the watershed using the CBP Phase 6 Watershed Model. The simulations use long-term average hydrology in order to remove annual variability in hydrology. This allows managers to understand changes in water quality trends in response to the implementation of pollution reduction actions. The simulations are also important for developing "what-if" scenarios managers can use to project future impacts of management actions on Bay water quality. Because of these differences in load assessment approaches, the two suites of indicators can report different pollutant load amounts in a particular year.

E. Adaptive Management

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

Factors influencing progress include the implementation of management practices; improved wastewater treatment technology; weather, including precipitation; and response of water quality conditions to management practices. Please see the 2017 WIP, 2025 WIP and Water Quality Standards Attainment & Monitoring Outcomes Management Strategy for a full discussion of these factors.

(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);
- Maintaining or enhancing wetlands and wetland filtering and nutrient retention capacity;
- 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;
- Enhancing financial capacity to oversee and implement MS4 and other stormwater programs;
- Enhancing Financial, technical and regulatory capacity to deliver priority conservation practices to priority watersheds; and
- Promoting BMP tracking, verification and reporting programs.

The primary monitoring gaps include (1) more frequent measures of dissolved oxygen to assess criteria attainment, (2) more spatial coverage of measurements to accurately assess DO conditions in the bay, and (3) more localized monitoring in watershed areas to assess the effects of BMPs.

For a fuller discussion of these gaps and how they are being addressed, please see the 2017 WIP, 2025 WIP and Water Quality Standards Attainment & Monitoring Outcomes Management Strategy.

(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) Assess Our Performance:

The Bay TMDL is supported by a rigorous accountability framework, including WIPs, short and long-term benchmarks (such as two-year milestones), a tracking and accountability system, and federal contingency actions that may be employed if jurisdictions do not meet their milestone and WIP commitments. STAR has set up several projects to better measure and explain progress towards water quality improvements and to pursue approaches to reduce uncertainties for models. BMPs are submitted through NEIEN on an annual basis and are used to assess progress through the Bay Program modeling tools. The CBP partners have endorsed (PSC, May 2012) an integrated approach that includes three primary pieces of information to measure progress toward achieving water quality standards in the Bay:

- Tracking and reporting of water quality management practices. These practices are expected to achieve reductions of nitrogen, phosphorus, and sediment by source and jurisdiction. These load reductions are estimates from the CBP models based on BMP implementation data submitted by the jurisdictions;
- Analyzing trends of nitrogen, phosphorus and sediment fluxes in the watershed. These trend estimates show long-term (i.e., 1985-current) and short-term (10 year) changes by normalizing the annual effects of streamflow variability. The normalized estimates are based on monitoring data collected as part of the CBP nontidal water quality monitoring program; and
- Assessing attainment of dissolved oxygen, chlorophyll-a, and water clarity/SAV standards. Attainment of these standards is based primarily on results from the CBP tidal water quality monitoring program.

(b) Ensure Adaptive Management

The CBP partnership has committed to take an adaptive management approach to the Bay TMDL and incorporate new scientific understandings into the implementation planning in two-year milestones and in Phase III following the midpoint assessment. The partnership uses annual monitoring information to modify models, which affect partnership decision-making. The CBP partnership will continue to examine the following questions to address implementation challenges and opportunities, through venues like the Strategy Review System (SRS) process, 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:

- What progress had been made in implementing practices for the Bay TMDL?
- 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.

River monitoring data have been collected according to field and laboratory methods and associated quality control protocols that are described by Chesapeake Bay Program (2017).

Beginning in 2012, all of the 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 analyses of data. A comparison of the WRTDS model to the previously used ESTIMATOR model is available -- see Moyer et al. 2012.

CBP's documentation of the Phase 6 Watershed Model:
https://cast.chesapeakebay.net/Documentation/ModelDocumentation.

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 developed by Grimm and Lynch (2000, 2005; Lynch and Grimm 2003) for wet deposition.

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

The methods for making these calculations have been reviewed internally at the Chesapeake Bay Program (the Nontidal Water Quality Workgroup). Portions of the data used in this indicator, such as the river input monitoring load estimates, have also passed the external peer-review process required during publication in scientific journals. A scientific manuscript documenting the methods used to estimate fluvial loads has been published (Keller et al. 2011).

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

A majority of the loads in this indicator are RIM loads, which are based on the peer-reviewed WRTDS model. Below-RIM point source loads are monitored. Atmospheric deposition and below-RIM nonpoint source loads, which make up a smaller portion of the overall total, are based on model values.

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

The Chesapeake Bay TMDL issued in 2010 set Bay watershed limits of 185.93 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), 12.54 million pounds of phosphorus, and 6,450 million 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*. Direct comparisons of these targets to loads from individual years should be avoided since individual years are not directly comparable to modeled, average load conditions.

(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)?

Every effort was made to minimize extrapolations beyond the available data.

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 29-31.** No.

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

Most procedures are published in peer reviewed or government publications. Refer to information in question 22 above.

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

Refer to information in question 22 above.

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

Each data provider has quality assurance protocols that they implement to ensure that high quality data are available for analysis. Refer to information in question 22 above.

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

Refer to information in question 22 above.

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

Refer to information in question 22 above.

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

(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?

Refer to information in question 22 above.

(35) For chemical data reporting: How are data below the 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? N/A

(36) Are there noteworthy limitations or gaps in the data record? No.

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.

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.)

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