Chesapeake Bay Program | Indicator Analysis and Methods Document
Nitrogen, Phosphorus, and Suspended Sediment Loads to the Bay
Updated October 9, 2018

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?

Discharge, nitrogen, phosphorus and suspended sediment concentrations are measured directly at the river input monitoring (RIM) sites. Wastewater discharges 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, 2018). Wastewater loads (i.e., delivered to the Bay) are estimated from EPA discharge monitoring (end-of-pipe) adjusted by delivery factors used in the CBPO HSPF watershed model 5.3.2. Load contributions from unmonitored areas (i.e., below fall-line) are calculated by scaling observed river input loads using information from the CBPO HSPF watershed model 5.3.2 (using scenario builder version 2.4). 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, 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) 1990-2017.

(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 April 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.
The estimates do not include inputs from the ocean or shoreline erosion.

(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?

Nitrogen: Approximately 240 million pounds of nitrogen reached the Bay during the 2017 water year (WY), which is below the 1990-2017 mean load of 327 million pounds. The 2017 WY load is 1 million pounds less than the 2016 WY load.

Phosphorus: Approximately 12.7 million pounds of phosphorus reached the Bay during the 2017 water year, which is below the 1990-2017 mean load of 19.6 million pounds. The 2017 WY load is 0.9 million pounds less than the 2016 WY load.

Sediment: Approximately 4,330 million pounds of sediment reached the Bay during the 2017 water year (WY), which is below the 1990-2017 mean load of 9,634 million pounds. The 2017 WY sediment load is 683 million pounds less than the 2016 WY load.

Flow: Annual average river flow to the Bay during the 2017 water year was 47.7 billion gallons per day (BGD), which is below the 1990-2017 mean flow of 52.4 BGD. The 2017 WY flow is 1.4 BGD more than the 2016 WY flow.

(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?
Method did not change this year, but did change in 2012 (refer to "Additional Information" section at the end of this document). However, prior year load estimates change each year this indicator is updated.

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 1990, the first year where all necessary data were available, the amount of nutrients delivered to the Bay from the watershed changes dramatically from year-to-year complicating efforts to determine trends through time.

(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 2017 and 2016 loads and flow in question 12 of this document.
The loads for nitrogen, phosphorus, and sediment are lower than last year, even though the river flow, which is based on precipitation, is higher than last year. This contrast might indicate positive progress in controlling the N, P, and SS loads from the Bay watershed through the management of various source sectors.

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

This indicator describes the amount of nitrogen, phosphorus and sediment delivered to Chesapeake Bay each year beginning in 1990. Scientists use a combination of the following information to estimate the loads to the Bay:

- river flow 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 tidal waters.

Pollutant loads to the 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).

As mentioned above, annual rain and snowfall influence the amount of water in rivers flowing to the Bay.

- These indicators track annual changes in river flow and the nitrogen, phosphorus and sediment loads to the Bay. It is important to calculate the amount of river flow and pollution loads to the Bay in any particular year in order to understand and explain trends in Bay water quality conditions.
- Other indicators, featured in the "Restoration" section of the CBP website, report computer-simulated nitrogen, phosphorus and sediment loads to the Bay (using the CBP phase 5.3 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. For example, in these indicators, the annual nitrogen load to the Bay in 2009 was 228 million pounds and phosphorus was 9.5 million pounds, representing the best estimate of how much nitrogen and phosphorus reached the Bay in 2009. In the other indicators, the simulation of 2009 loads was 282.66 million pounds of nitrogen and 19.23 million pounds of phosphorus. Those simulations do not represent how much nitrogen and phosphorus reached the Bay in 2009 since they are based on long-term average hydrology rather than the actual amount of water flowing to the Bay in 2009.

Each day, billions of gallons of fresh water 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.

There is a further accounting for deposition directly onto the water surface of the bay and the waterways of the watershed that contributes to overall pollution levels experienced by the bay.

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 technical information; 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?
Gaps that the Bay Watershed jurisdictions continue to address include:

- Financial capacity to oversee and implement MS4 and other stormwater programs
- Financial, technical and regulatory capacity to deliver priority conservation practices to priority watersheds
- 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 and Workplan.

(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. Integrating the following pieces of information will allow for better assessment of our performance:

- Reductions of nitrogen, phosphorus and sediment by source, jurisdiction and overall load reduction associated with the implementation of BMPs. These load reductions are estimates from the CBP models based on BMP implementation data submitted by the jurisdictions.
- Changes of in-stream nitrogen, phosphorus and sediment concentrations and loads as estimated by flow-adjusted trends of nitrogen, phosphorus and sediment. These estimates show long-term (25 year) and shorter 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.
- Attainment of Chesapeake water quality standards for dissolved oxygen, chlorophyll-a, water clarity/SAV standards. Attainment of these standards is based primarily on results from the CBP tidal water quality monitoring program.

The CBP partnership will enhance the analysis and explanation of monitoring information as part of the Bay TMDL's midpoint assessment.

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.
- Analyzing trends of nitrogen, phosphorus and sediment in the watershed.
- Assessing attainment of dissolved oxygen, chlorophyll and water clarity/SAV standards.

(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, 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.

Beginning in 2012, all of the RIM site loads are determined using an enhanced statistical technique generally referred to as 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 HSPF model
http://www.chesapeakebay.net/about/programs/modeling/53/

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 Chesapeake Bay and its tidal tributaries meeting their water quality criteria for dissolved oxygen, water clarity/SAV and chlorophyll *a* (US EPA 2010). 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?

Yes. Most procedures are published in peer reviewed or government publications. Refer to information about USGS WRTDS model in response to question 22 above; watershed modeling (Linker et al. 2000).

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

Refer to information about USGS WRTDS model in response to question 22 above; U.S. EPA wastewater- and watershed modeling (Linker et al. 2000).

(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. For USGS river input monitoring, refer to information about USGS WRTDS model 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 about USGS WRTDS model in question 22 above.

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

Refer to information about USGS WRTDS model 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 about USGS WRTDS model 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.

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

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.

References

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