The State of Chesapeake Bay Watershed Modeling

Comparing the Updated Phase 6 "Total Maximum Daily Load" Watershed Model to the Former Phase 5.3.2 Model

ENVIRONMENTAL INTEGRITY PROJECT

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Written by Abel Russ of the Environmental Integrity Project.

THE ENVIRONMENTAL INTEGRITY PROJECT

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CONTACTS:

For questions about this report, please contact:

Tom Pelton, Environmental Integrity Project, (202) 888-2703 or tpelton@environmentalintegrity.org

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Summary

The ongoing effort to restore the Chesapeake Bay – the “Total Maximum Daily Load,” or TMDL – reached its midpoint in 2017. That year was halfway between the beginning of the current cleanup process (in 2009) and the target date of 2025 for implementing all of the strategies necessary to restore the health of the Bay. In 2017, the Bay states and Washington, D.C. went through a “midpoint assessment,” looking back at the progress they had made since 2009 using a model of pollution loads from the watershed known as the “phase 5.3.2” model. But in 2017 the Bay states also started looking ahead, trying to figure out how to achieve their pollution reduction targets, and they did so using a new model known as “phase 6.” The phase 6 model was the foundation for the revised 2025 targets that the Bay states are now using to develop their third round of planning documents, known as Watershed Implementation Plans. The Chesapeake Bay Program ran both models – phase 5.3.2 and phase 6 – for the year 2017.

This white paper is intended to provide a very broad-brush assessment of how our understanding of TMDL progress might have been affected by the transition from one model to another. It does not delve into the technical differences between the two models, but instead focuses on model outputs. Our analysis generated the following observations:

1. The phase 6 model estimates of average loads are slightly lower than observed loads, which is to be expected given underlying model assumptions. Average phase 6 load estimates are closer than phase 5.3.2 estimates to observed loads for nitrogen and sediment. For phosphorus, the phase 5.3.2 model is closer to observed loads than the phase 6 model.

2. The phase 5 and phase 6 models, and observed loads, are all in agreement about nitrogen trends, showing annual declines in nitrogen load of roughly 1 percent.

3. For phosphorus, the phase 5.3.2 and phase 6 models are in agreement with each other (a decline of roughly 2 percent per year), but this is in contrast to trends in observed phosphorus loads, which have been declining at a much slower rate of 0.3 percent per year.

4. As with phosphorus, both models fail to simulate trends in observed sediment load. Observed sediment load has actually been increasing modestly over time (at roughly 0.6 percent per year), while both models estimate declining sediment load.

5. **Agriculture**
    - Compared to the phase 5.3.2 model, the phase 6 model shows more nitrogen coming from agriculture, but less phosphorus and sediment. Part of the difference with respect to phosphorus and sediment may be a change in how loads are assigned; much of the phosphorus and sediment that was attributed to agricultural land in phase 5.3.2 is now attributed to the natural “streams” category.

- Trends in agricultural nitrogen are similar in the two models, showing an annual decline of 0.4 or 0.5 percent between 2009 and 2017. For agricultural phosphorus, the phase 6 model shows a slower decline (1.2 percent per year) than the phase 5.3.2 model (3.7 percent per year). For sediment, the opposite is true, and the phase 6 model shows a more rapid decline (2.3 percent per year) than the phase 5.3.2 model (1.4 percent per year).
- Trends in state-level agricultural pollution have changed in mixed ways.
  - Pennsylvania is making better progress under the phase 6 model. Agricultural nitrogen loads were increasing under phase 5.3.2, but are declining (modestly) under phase 6. Agricultural phosphorus and sediment loads are declining more rapidly than they were using the phase 5.3.2 model.
  - Maryland, on the other hand, is making less progress. Looking at phase 6 model estimates, all three pollutants are declining more slowly than they were with phase 5.3.2.
  - Virginia is mixed, with slower agricultural nitrogen and phosphorus reductions using phase 6, but more rapid agricultural sediment reductions.

6. Stormwater

- Stormwater runoff from developed land continues to be a large source of nutrient and sediment pollution in the phase 6 model. The phase 6 model shows increasing trends for nitrogen, phosphorus and sediment, where the phase 5.3.2 model only showed increasing trends for nitrogen. Reversing these trends will be a key challenge for the Bay states.
- Stormwater nitrogen loads in 2017 were 41.3 million pounds using the phase 5.3.2 model (18 percent of total nitrogen loads), and 39.6 million pounds using phase 6 (16 percent of total). Stormwater nitrogen loads are increasing in all of the Bay states other than West Virginia and Washington, D.C.
- Stormwater phosphorus loads are very similar in the two models, at 18-20 percent of total load in 2017. Stormwater phosphorus loads are increasing in Delaware, Pennsylvania and Virginia. Stormwater phosphorus loads are declining in the other states, but not as quickly as they were using the phase 5.3.2 model.
- Stormwater sediment loads are lower in phase 6 (1.7 billion pounds, or 19 percent of total sediment loads) than they were in phase 5.3.2 (1.9 billion pounds, or 25 percent of the total). However, much or all of this difference could be accounted for by the new "stream" category, which is assigned over half of the total sediment load in phase 6 and which includes sediment that originally came from upstream land uses. Stormwater sediment loads are increasing in Delaware, Maryland, Virginia, and West Virginia.

7. **State-by-state progress.** The shift from phase 5.3.2 to phase 6 has had mixed effects on each state's relative contribution to total Chesapeake Bay loads, progress since 2009, and the necessary reductions between now and 2025. The states with the largest relative pollution loads – Maryland, Virginia and Pennsylvania – continue to face significant challenges as they look toward 2025 targets:

   - **Washington, D.C.** is already meeting its 2025 pollution targets under both models.

   - **Delaware** continues to be a relatively minor contributor to Bay loads, accounting for no more than 3 percent of any one pollutant. This is true under both models. The phase 6 model suggests that Delaware has been making progress as quickly (for phosphorus) or more quickly (for nitrogen and sediment) than the phase 5.3.2 model implied. However, both models show that Delaware will have to double its rate of nitrogen reductions to meet the 2025 target. Delaware is on track to meet its phosphorus and sediment targets in both models.

   - **Maryland** has to work harder, according to the phase 6 model, and doesn't seem prepared.
     - To begin with, the size of Maryland's problem is larger using the phase 6 model. For example, Maryland's nitrogen load in 2017 was 47 million pounds using the phase 5.3.2 model, but 54 million pounds using the phase 6 model.
     - Maryland's problem is larger in relative terms, as well: Maryland's slice of the total pie (total Chesapeake Bay loads) is larger in phase 6 for all three pollutants. Maryland's share of the nitrogen load increased from 15 percent (phase 5.3.2) to 22 percent (phase 6). Maryland's share of the phosphorus load increased from 18 percent to 25 percent. And Maryland's share of the sediment load increased from 15 percent to 42 percent, making it the largest source of sediment to the Bay.
     - The phase 6 model suggests that Maryland has not been making progress as quickly as the phase 5.3.2 model implied. Nitrogen reductions since 2009 were happening at 1.6 percent per year under phase 5.3.2, but the phase 6 model cuts that rate of decline in half, to 0.7 percent per year. The rate of phosphorus decline has changed from 2.6 percent per year (phase 5.3.2) to 1.1 percent per year (phase 6). Maryland's progress with respect to sediment has effectively vanished – it was reducing sediment loads by 2.1 percent per year under phase 5.3.2, but phase 6 shows a much smaller decline of 0.1 percent per year.
     - To meet its 2025 nitrogen targets, Maryland will have to triple its rate of overall nitrogen reductions, increase agricultural nitrogen reductions

by a factor of five, and reverse course on urban stormwater loads (which have been increasing).
    - In short, the phase 6 model suggests that Maryland is not making progress as quickly as we assumed, and will have to invest significantly greater effort to meet its targets. Yet Maryland's draft phase III Watershed Implementation Plan is effectively a "business as usual" plan that seems to operate on the flawed assumption that the current approach is adequate.

- **New York** is roughly in the same position as it was using the phase 5.3.2 model, on track to meet phosphorus and sediment goals, but not yet on track to meet the nitrogen target.
    - New York is responsible for 6 percent of the nitrogen, 4 percent of the phosphorus, and 4 percent of the sediment reaching the Chesapeake Bay each year, according to the phase 6 model. These numbers are basically unchanged from the phase 5.3.2 model.
    - Under the phase 5.3.2 model, New York's nitrogen loads appeared to be increasing between 2009 and 2017. This is no longer the case, but New York is still significantly off track. According to the phase 6 model, nitrogen loads have been declining at a rate of 0.4 percent per year. To meet 2025 targets, New York will have to accelerate this to 2.7 percent per year.
    - New York is on track to meet its phosphorus target ahead of schedule under both models.

- **Pennsylvania** continues to face a steep uphill climb.
    - Using either model, Pennsylvania is the largest source of nitrogen loads, and the state that will have to generate most of the remaining reductions in both nitrogen and phosphorus.
    - The recent rate of nitrogen reductions is not nearly good enough under either model, though things look slightly better using the phase 6 model. The new model suggests that Pennsylvania will have to achieve a six-fold increase in the rate of nitrogen reductions, from 0.8 percent per year to 4.7 percent per year.
    - Pennsylvania is also the only jurisdiction not meeting or on track to meet its 2025 phosphorus target. The current rate of phosphorus reductions will have to be modestly accelerated, from 2.1 percent per year to 2.8 percent per year.
    - In some rosier news for Pennsylvania, the phase 6 model shows that the state has been making more progress since 2009 then the phase 5.3.2 model implied. Nitrogen loads had been increasing using the phase 5.3.2 model, but now appear to be flat or slowly declining (at a rate of 0.1 percent per year). The rate of phosphorus decline has

changed from 1.0 percent per year (phase 5.3.2) to 1.4 percent per year (phase 6). The rate of sediment decline has changed from 0.9 percent per year (phase 5.3.2) to 2.6 percent per year (phase 6).

- **Virginia** is generally on track to meet its 2025 goals, though it will have to work harder to reduce agricultural and stormwater loads.
    - Virginia's slice of the total pie (total Chesapeake Bay watershed loads) is a little smaller for all three pollutants using the phase 6 model. Virginia's share of nitrogen loads has decreased from 26 percent (phase 5.3.2) to 23 percent (phase 6). Virginia's share of phosphorus loads has decreased from 43 percent (phase 5.3.2) to 41 percent (phase 6). And Virginia's share of sediment loads has decreased from 45 percent (phase 5.3.2) to 35 percent (phase 6).
    - Virginia is on track to meet its 2025 nitrogen target ahead of time in both models, and is already meeting its 2025 phosphorus target in the phase 6 model.
    - However, the phase 6 model shows that Virginia is not making as much progress on agricultural pollution as the phase 5.3.2 model implied. The rate of decline in agricultural nitrogen loads has changed from 2.7 percent per year (phase 5.3.2) to 0.5 percent per year (phase 6). The rate of decline in agricultural phosphorus loads has changed from 5.9 percent per year to 0.6 percent per year.

- **West Virginia** is responsible for less than 5 percent of each pollution under both models. The phase 5.3.2 model showed that the state was on-track to meet its 2025 targets. The phase 6 models shows that the state is already meeting both targets.

I. Background

The Chesapeake Bay Total Maximum Daily Load (TMDL) is a "pollution diet" for the Chesapeake Bay. The U.S. EPA and the Bay states (or "jurisdictions," as they include Washington, D.C.) designed the TMDL to restore the Chesapeake Bay ecosystem and its designated uses. The Bay has long been impaired by excessive levels of nitrogen, phosphorus and sediment. The 2010 TMDL document described the problem as follows:

> Most of the Chesapeake Bay and its tidal waters are listed as impaired because of excess nitrogen, phosphorus and sediment. These pollutants cause algae blooms that consume oxygen and create "dead zones" where fish and shellfish cannot survive, block sunlight that is needed for underwater Bay grasses, and smother aquatic life on the bottom. The high levels of nitrogen, phosphorus and sediment enter the water from agricultural operations, urban and suburban stormwater runoff, wastewater facilities, air pollution and other

> sources, including onsite septic systems. Despite some reductions in pollution during the past 25 years of restoration due to efforts by federal, state and local governments; non-governmental organizations; and stakeholders in the agriculture, urban/suburban stormwater, and wastewater sectors, there has been insufficient progress toward meeting the water quality goals for the Chesapeake Bay and its tidal waters.[1]

The ultimate goal of the TMDL is to limit the loads of nitrogen, phosphorus and sediment to amounts that are compatible with a healthy Bay ecosystem. The target date for completing the necessary pollution reduction strategies is 2025.[2]

Although the 2010 document described above can be described as "the TMDL," the TMDL is actually an ongoing, collaborative, iterative process. Over time, the models used to simulate the Bay and the Bay watershed have evolved, and so have the 2025 targets for each state. In parallel, the Bay jurisdictions have developed a series of Watershed Implementation Plans (WIPs), which detail "how and when the six Bay jurisdictions and the District of Columbia will meet pollution allocations."[3] In 2017, the TMDL process included a "midpoint assessment," an opportunity to evaluate progress to date and the pollution reductions that still had to be achieved by 2025.

The history of TMDL modeling is briefly summarized in the documentation for the current, phase 6 model.[4] The phase 6 model was completed in 2017 "for application in the 2017 Midpoint Assessment."[5] Leading up to the midpoint assessment, the Bay jurisdictions had been working with WIPs and pollution targets that were based on a model known as "phase 5," with the most recent version of that model being phase 5.3.2. Starting in 2017, the Bay Program started using the new phase 6 model. The phase 6 model differs from earlier models in a number of ways, including:

- The phase 6 model uses newer and better data for key inputs such as climatic variables, land use, and nutrient inputs;
- is more transparent and accessible to the public;
- has a higher (more detailed) spatial resolution;
- incorporates shoreline erosion loads;
- attributes loads from streambank erosion and scouring to a natural source ("streams"), where past models assigned these loads to upstream land uses; and

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[1] U.S. EPA, Chesapeake Bay TMDL Document at ES-3 (Dec. 29, 2010), https://www.epa.gov/chesapeake-bay-tmdl/chesapeake-bay-tmdl-document.

[2] See U.S. EPA, Chesapeake Bay TMDL Document (Dec. 29, 2010) at ES-1 ("The TMDL is designed to ensure that all pollution control measures needed to fully restore the Bay and its tidal rivers are in place by 2025"), https://www.epa.gov/chesapeake-bay-tmdl/chesapeake-bay-tmdl-document.

[3] Id. at ES-1.

[4] Chesapeake Bay Program, Phase 6 Watershed Model Final Model Documentation for the Midpoint Assessment, Section 1, Overview, at 1-1 to 1-2 (May 21, 2018), https://cast.chesapeakebay.net/Documentation/ModelDocumentation

[5] Id. at 1-1.

- features improved phosphorus loading submodels that emphasize factors like stormwater and soil phosphorus levels

As the Bay jurisdictions develop their phase III WIPs, they are using pollution targets based on this new phase 6 model.

The midpoint assessment year therefore serves as an important juncture. In 2017, the modeling used to simulate the Bay watershed changed, the targets for each state changed, and in fact the estimates of progress achieved to date (between 2009-2017) also changed. The Bay jurisdictions went into 2017 with a picture of how well they were doing and how much work they still had to do, and in 2017 that picture changed.

The following white paper presents an outsider's simplistic, high-level perspective on how the change from the phase 5.3.2 watershed model to the phase 6 watershed model affected our understanding of where pollution is coming from, how much progress the Bay jurisdictions have made, and how much work remains to be done. We routinely compare data from three sources:

- Outputs from the phase 5.3.2 model were obtained from the Bay Program's "Chesapeake Bay TMDL Tracker" website.[6]
- Outputs from the phase 6 model outputs were obtained from the Bay Program's Chesapeake Assessment Scenario Tool (CAST) website.[7]
- In addition, from time to time we compare model estimates to what we refer to as "observed" loads, or "estimated actual" loads, which make use of flow and concentration data from River Input Monitoring (RIM) stations, discharge monitoring data for point sources downstream of the RIM stations, and modeled loads for nonpoint sources downstream of the RIM stations. The cumulative total of these inputs is the best estimate of actual loads for a given year. Observed load data were obtained from the Bay Program's Chesapeake Progress website.[8]

II. Watershed Overview

In order to compare the two models in broad strokes, we looked at (a) average loads over the longest available periods of comparison, (b) bay-wide loads over time, (c) the contribution of each jurisdiction to total loads, and (d) the contribution of each sector to total loads. Finally, we also compared the difference between 2017 loads and 2025 targets under each model, using 2017-era targets for the phase 5.3.2 model and Phase III WIP targets for the phase 6 model.

[6] Chesapeake Bay Program, Chesapeake Bay TMDL Tracker, https://tmdl.chesapeakebay.net/ (data downloaded on Feb. 7, 2019).
[7] Chesapeake Bay Program, Chesapeake Assessment Scenario Tool (CAST), https://cast.chesapeakebay.net/ (data downloaded in February – April 2019).
[8] https://www.chesapeakeprogress.com/clean-water/water-quality.

a. Average Loads

For any given year, we should not expect the model to generate load estimates that match observed data for at least three reasons. First, the model estimates long-term loading rates given a particular snapshot of land use and nutrient inputs, assuming 1991-2000 weather patterns. For example, the 2017 scenario run assumes that 2017 land use – including nitrogen and phosphorus inputs to soil – will remain constant, and that weather patterns will resemble what they were in 1991-2000, and then simulates a multi-year average annual load. Over long periods of time, if 1991-2000 were truly representative of average precipitation patterns, then we would expect to see actual precipitation and flow values converge on the 1991-2000 estimates, and this would bring the modeled loads and actual loads into closer agreement.

Second, the model simulates soil phosphorus dynamics over a 25-year period. If, for example, soil phosphorus levels were very high in 2017 (due to a history of high fertilizer and manure applications), but phosphorus applications in 2017 were lower than the amount taken up by growing crops, then the model would simulate a gradual reduction in soil phosphorus over the 25-year period. This would in turn lead to gradual reductions in phosphorus loads.

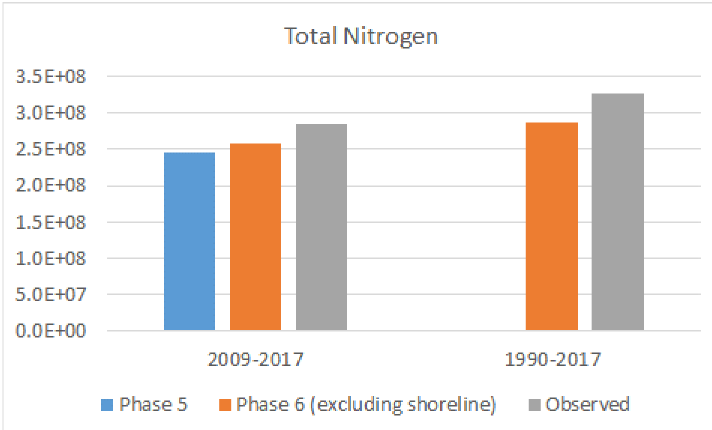
In addition, only the phase 6 model quantifies the nutrient and sediment load from shoreline erosion. This section is intended to show how the overall picture of the Chesapeake Bay differs between the two models and between the models and observed data, so the figures in this section omit shoreline loads.

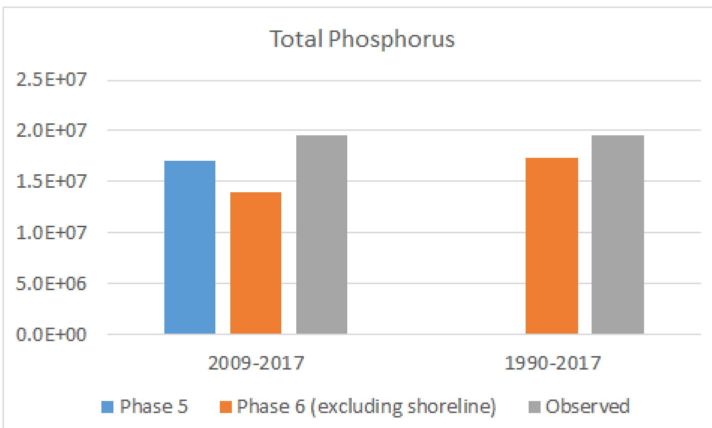
With these caveats in mind, **Figures 1 through 3** compare phase 5.3.2 and phase 6 model simulations to observed loads over two periods of time: 2009-2017 (the maximum range of dates with load estimates for both models) and 1990-2017 (the maximum range of dates with observed data and phase 6 model estimates). For nitrogen, the phase 6 model tends to underestimate observed loads, but only slightly (by 9 percent), and it does a better job than the phase 5.3.2 model. For phosphorus, the phase 6 model underestimates observed loads over the 2009-2017 time period, and does so by a greater margin (29 percent) than the phase 5.3.2 model (13 percent). Over the longer 1990-2017 time period, average phase 6 estimates are 12 percent lower than observed loads.

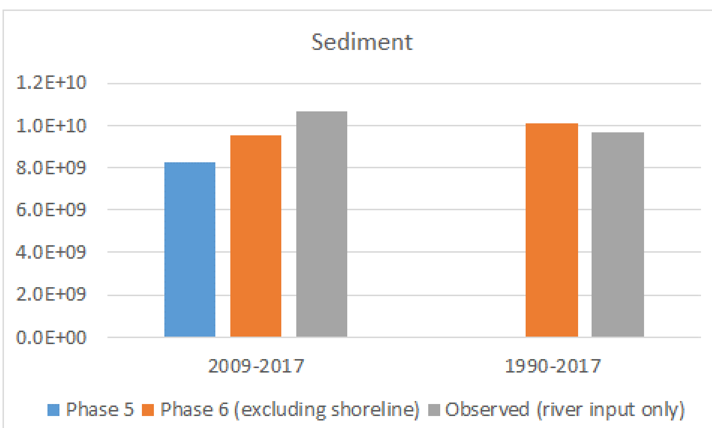
Sediment load observations only include loads passing through the RIM stations, and do not include any loads – erosion or otherwise – from the coastal plain below the RIM stations. These river input sediment loads over the 2009-2017 period were on the order of 10 billion pounds. The average phase 6 model estimate over the same time period is similar (11 percent lower) and closer than the phase 5.3.2 model estimate (which was 23 percent lower). Over the longer 1990-2017 time period, the average phase 6 model estimate is slightly (5 percent) higher than the observed RIM station loads.

The nutrient and sediment results are not necessarily problematic. Modeled loads *should be* slightly lower than observed loads, because the model is forward-looking, estimating average loads by assuming that current land use management is constant for 25 years. Observed loads, on the other hand, are largely the product of past land use management.

Figures 1 through 3: Long-term average nitrogen, phosphorus and sediment loads (delivered, bay-wide, in pounds) in the phase 5.3.2 and phase 6 models and in observed ("estimated actual") data.







b. Trends

The maximum range of dates with load estimates from both models is 1985 to 2017, with a large gap between 1985 and 2009 for phase 5.3.2 model estimates. **Figure 4** shows total nitrogen loads over this time period, again excluding shoreline erosion. Phase 6 loads are consistently 4-8 percent higher than phase 5.3.2 loads, but both models show very similar trends over time, with nitrogen reductions of roughly 1 percent per year.

Figure 4: Bay-wide delivered nitrogen load (millions of pounds, excluding shoreline erosion).

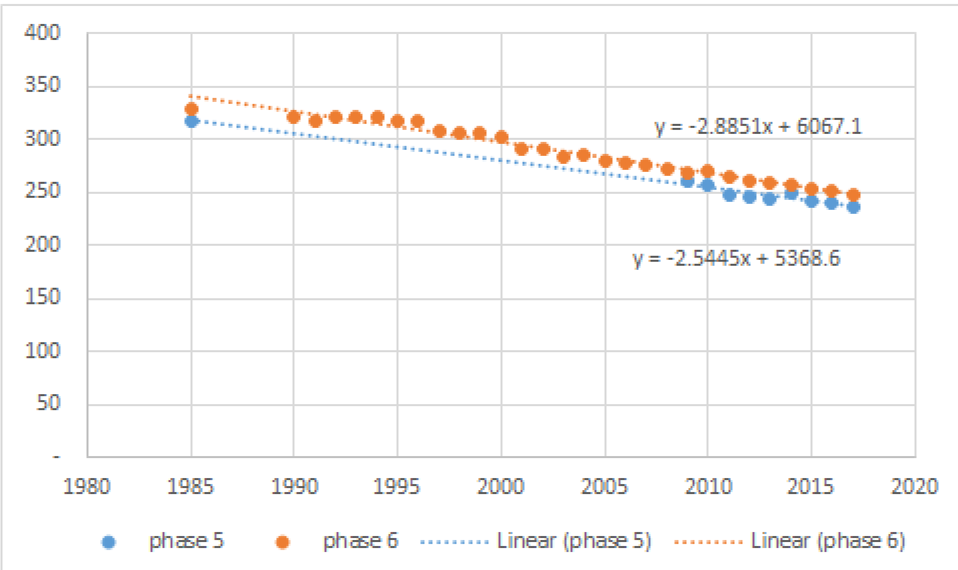
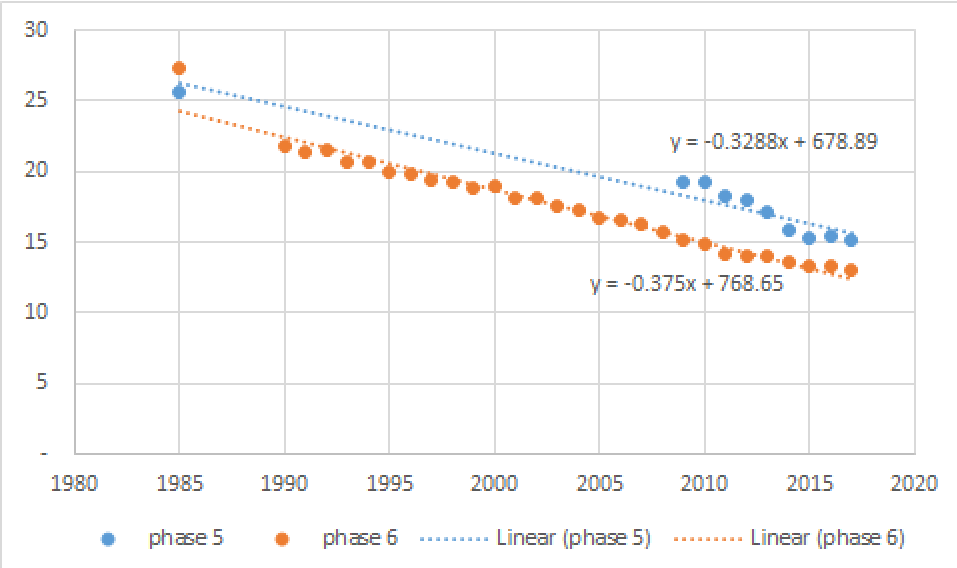


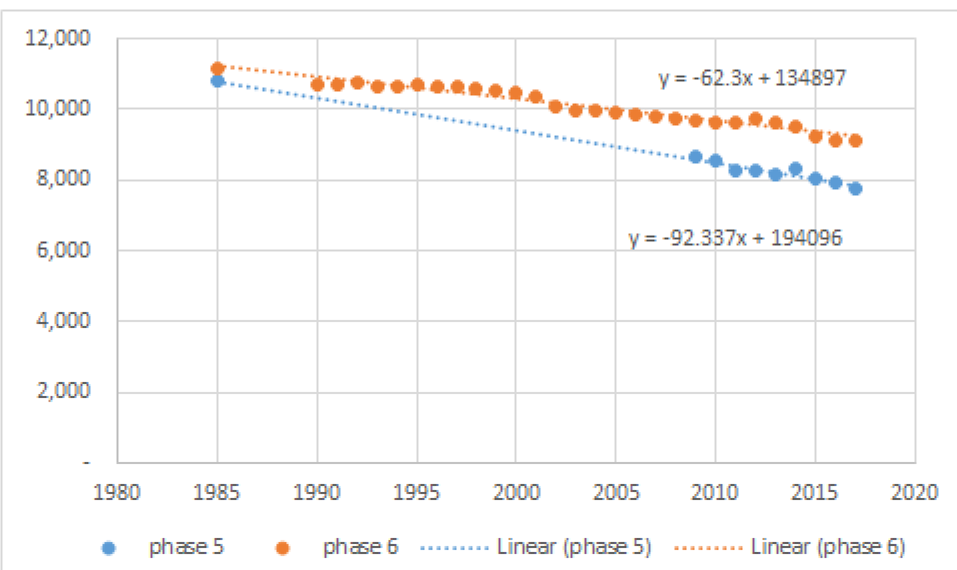
Figure 5 shows total phosphorus loads. Here the two models disagree about patterns over time. Over the 1985-2017 time period, the phase 6 model shows a slightly more rapid decline in phosphorus loads, of roughly 375,000 pounds per year (2.1 percent per year), than the phase 5.3.2 model, which shows a decline of 330,000 pounds per year (1.8 percent per year). But over the more recent 2009-2017 time period, the phase 6 model shows a less rapid decline in phosphorus loads: In the phase 6 model, loads decline by about 260,000 pounds per year (1.9 percent per year); in the phase 5.3.2 model, loads decline by 600,000 pounds per year (3.5 percent per year).

Figure 5: Bay-wide delivered phosphorus load (millions of pounds, excluding shoreline load)



For sediment, the phase 6 model simulates a significantly slower rate of decline than the phase 5.3.2 model. According to the phase 6 model, sediment loads have declined at a rate of 62 million pounds per year since 1985 (0.6 percent per year). The phase 5.3.2 model, by contrast, estimated a rate of decline of over 90 million pounds per year (1.1 percent per year). It is worth noting that both models are inconsistent with long-term trends in the "river input" sediment loads, which *increased* by 0.6 percent per year between 1990 and 2017.[9]

Figure 6: Bay-wide delivered sediment load (millions of pounds), excluding shoreline erosion



[9] According to data found at the Bay Program's ChesapeakeProgress website: https://www.chesapeakeprogress.com/clean-water/water-quality.

Table 1 provides summary trend statistics for 1985-2017 and 2009-2017 for both the phase 5.3.2 and the phase 6 models. **Table 1** also provides long-term trends in actual loads, which are available for the 1990-2017 time period and, for sediment, are limited to "river input" loads. **Table 1** shows that both models do a good job of simulating trends in nitrogen load. However, the models are not good at simulating long-term phosphorus and sediment trends. Real-world phosphorus loads have been declining at a rate of 0.3 percent per year since 1990. The phase 6 model assumes a rate of decline that is over 6 times greater, at 2 percent per year, over the same time period. Similarly, real-world sediment loads have been *increasing* at a rate of 0.6 percent per year, while the phase 6 model assumes a decline of 0.6 percent per year.

Table 1: Changes in loads over time (percent/year) in the phase 5.3.2 model, the phase 6 model, and the real world.

Year	Nitrogen	Phosphorus	Sediment
2009-2017			
Phase 5.3.2	-1.1%	-3.5%	-1.2%
Phase 6	-1.1%	-1.9%	-0.9%
1985-2017			
Phase 5.3.2	-1.0%	-1.8%	-1.1%
Phase 6	-1.0%	-2.1%	-0.6%
1990-2017			
Phase 6	-1.0%	-2.0%	-0.6%
Estimated actual	-1.2%	-0.3%	+0.6%[10]

Part of the problem may be related to climate change. One of the Bay Program files that we reviewed made the observation that sediment loads in high-flow years appear to be increasing over time.[11] It appears that the Bay Program isolated years with flow volumes greater than 60 or 65 billion gallons per day. For these years, both the total sediment load and the flow-adjusted sediment load appear to be increasing. Figure 4 shows flow-adjusted sediment loads expressed as mg/L. The same trend can be seen for phosphorus (Figure 5). These data show that high phosphorus and sediment loads are being driven by something other than total flow volume. That other factor is very likely to be precipitation intensity. As the Bay region sees more frequent and more intense storm events, it is likely to see more frequent and more intense "dumps" of phosphorus and sediment into the Bay. The phase 6 model addresses this dynamic, in part, by accounting for stormflow and runoff effects in its modeling of phosphorus load. However, the phase 6 model does not account for precipitation intensity effects on phosphorus runoff from developed land, or on the effects of

[10] Id. Sediment loads only reflect the "river input" loads, or the loads monitored at the river input monitoring stations, and therefore do not reflect loads from the tidal parts of the watershed.

[11] Chesapeake Bay Program, Chesapeake Progress, "data" link (https://www.chesapeakeprogress.com/files/Data_2017_NPS_Loads_and_River_Flow_10-12-2018.xlsx), "S Load and Flow" tab. A graph in this tab entitled "Sediment load – high river flow years only" has the parenthetical subtitle "loads in high flow years seem to get bigger over time".

climate change on the effectiveness of pollution-reduction strategies known as Best Management Practices (BMPs).

Figure 7: River input sediment loads in high-flow years, expressed as mg/L.[12]

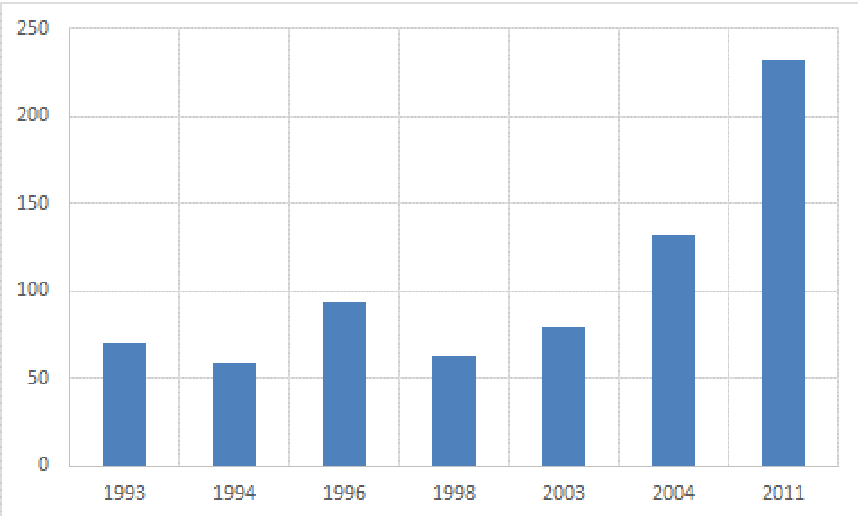
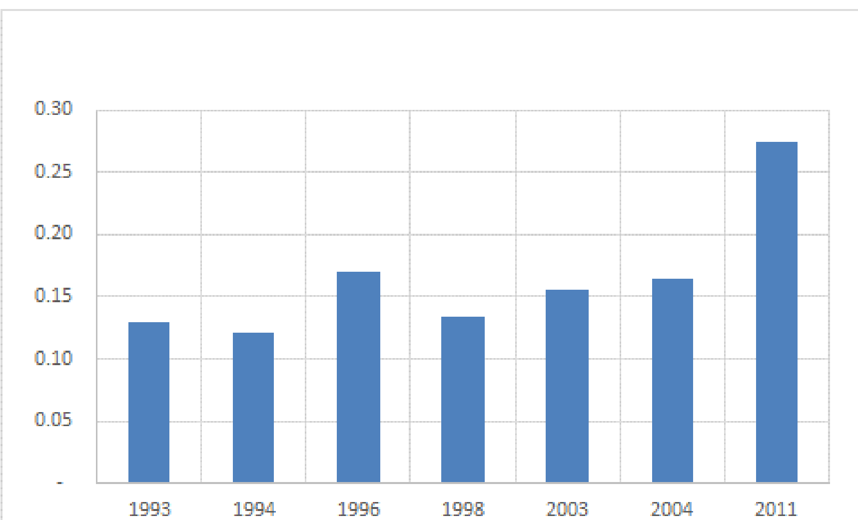


Figure 8: Bay-wide phosphorus loads in high-flow years, expressed as mg/L.[13]



[12] Data from Chesapeake Progress (supra note 11). "High-flow years" defined as years with daily average flow volume in excess of 60 billion gallons per day. Loads (in tons per year) were divided by flow (in gallons per day) and converted to units of mg/L with the appropriate conversion factors.
[13] See supra note 12.

III. Bay Jurisdictions

a. 2017 Loads

Tables 2 through 4 show 2017 loads of nitrogen, phosphorus and sediment by jurisdiction using both the phase 6 and the phase 5.3.2 models. The following observations can be made:

- **Nitrogen (Table 2):** As discussed above, total, bay-wide nitrogen loads are slightly higher under the phase 6 model, by about 5 percent. Breaking this down by jurisdiction, we see that the phase 6 model predicts significantly higher nitrogen loads from Delaware, Maryland, and West Virginia, and slightly lower nitrogen loads from Pennsylvania. However, if we look at each jurisdiction in terms of its contribution to total load, we see that the two models are in rough agreement. Pennsylvania, for example, was responsible for 45 percent of the total load under phase 5.3.2, and 43 percent of the total load under phase 6. Perhaps the most notable change is Maryland's share of the total load, which increases from 15 percent (phase 5.3.2) to 22 percent (phase 6).
- **Phosphorus (Table 3):** With phosphorus, there are more significant differences by jurisdiction. Maryland's phosphorus load is 35 percent higher in the phase 6 model (in part due to new shoreline erosion load estimates), and D.C.'s phosphorus load is slightly higher, while the remaining jurisdictions' loads are all lower. Looking at each jurisdiction in terms of its contribution to total load, we see a pattern similar to that for nitrogen. Most jurisdictions are responsible for a slightly smaller slice of the pie under phase 6, but Maryland's share increases from 18 percent to 25 percent.
- **Sediment (Table 4):** The two models estimate significantly different sediment loads, both in total bay-wide load, which is 134 percent higher in phase 6, and in spatial distribution. Once again, Maryland's share of the 2017 load changes the most, going from 15 percent (phase 5.3.2) to 42 percent (phase 6). Again, this change for Maryland is in large part due to new shoreline erosion loads. Pennsylvania and Virginia, by contrast, see their shares of the total load decrease significantly in the phase 6 model.

Table 2: NITROGEN – 2017 delivered loads by jurisdiction (millions of pounds)

2017	Phase 5.3.2	% of total load	Phase 6	% of total load
Delaware	4.1	1%	6.5	3%
D.C.	1.6	0%	1.5	1%
Maryland	46.9	15%	54.2	22%
New York	10.9	7%	14.3	6%
Pennsylvania	111.0	45%	107.3	43%
Virginia	55.9	26%	58.2	23%
West Virginia	5.1	5%	7.8	3%
TOTAL	235.5		249.8	

Table 3: PHOSPHORUS –2017 delivered loads by jurisdiction (millions of pounds)

2017	Phase 5.3.2	% of total load	Phase 6	% of total load
Delaware	0.27	2%	0.12	1%
D.C.	0.07	0%	0.08	1%
Maryland	2.72	18%	3.67	25%
New York	0.75	5%	0.63	4%
Pennsylvania	4.20	28%	3.80	26%
Virginia	6.43	43%	6.12	41%
West Virginia	0.65	4%	0.43	3%
TOTAL	15.10		14.84	

Table 4: SEDIMENT – 2017 delivered loads by jurisdiction (millions of pounds)

2017	Phase 5.3.2	% of total load	Phase 6	% of total load
Delaware	81	1%	26	0%
D.C.	16	0%	40	0%
Maryland	1,185	15%	7,575	42%
New York	322	4%	666	4%
Pennsylvania	2,377	31%	2,934	16%
Virginia	3,475	45%	6,455	35%
West Virginia	331	4%	556	3%
TOTAL	7,787		18,253	

b. Remaining Reductions

The differences in absolute load discussed above are interesting, but they do not translate into conclusions about how well each state is doing, or how much work remains to be done. For example, the fact that the phase 6 model estimates significantly higher nutrient and sediment loads for Maryland does not necessarily mean that Maryland is now further away from its pollution reduction targets, because those targets have also changed. **Tables 5 through 7** show that the new 2025 targets have changed in ways that are roughly consistent with the distribution of load in 2017. For example, Maryland's 2017 phosphorus load is roughly 35 percent higher in the phase 6 model, but its phase III WIP target for phosphorus is 31 percent higher than its phase II target.

A different way to look at the status of each jurisdiction is to compare its 2017 loads to the 2025 targets for nutrients.[14] **Tables 5 and 6** show that each state is in a different place with respect to 2025 targets:

[14] There are currently no 2025 targets for sediment at the Bay Program level, though Maryland has developed its own sediment targets.

Delaware must make significantly greater nitrogen reductions under phase 6, and must also make modest phosphorus reductions. Delaware's nitrogen gap – the amount of nitrogen it will have to reduce to meet 2025 targets – has increased from 0.7 million pounds per year (phase 5.3.2) to 1.9 million pounds per year (phase 6). Expressed as a fraction of 2017 load, Delaware had to make an 18 percent reduction under phase 5.3.2, but must now make a 30 percent reduction. For phosphorus, Delaware had been slightly below its 2025 target under phase 5.3.2 but is now slightly above its target and must make a 9 percent reduction.

D.C. is already below the 2025 targets for both pollutants in both models.

Maryland must make significantly greater nitrogen reductions. The state's nitrogen gap has increased from 5.7 million pounds (phase 5.3.2) to 8.4 million pounds (phase 6). Expressed as a fraction of 2017 load, Maryland had to make a 12 percent reduction under phase 5.3.2, but must now make a 16 percent reduction. Although Maryland is still currently ahead of its 2025 phosphorus target, 2017 loads were very close to that target, leaving no room for future increases.

New York is essentially in the same place with respect to nitrogen, and a little better off with respect to phosphorus. New York's nitrogen gap has increased from 2 to 2.8 million pounds in absolute terms, but both models show that New York will have to reduce 2017 loads by 19 percent .

Pennsylvania will have to make greater nitrogen and phosphorus reductions under the phase 6 model. Pennsylvania's nitrogen gap has increased from 32 million pounds (29 percent of 2017 load) to 34.1 million pounds (32 percent of 2017 load). Pennsylvania's phosphorus gap has increased from 0.63 million pounds (15 percent of 2017 load) to 0.76 million pounds (20 percent of 2017 load). It is also worth noting that because the other large jurisdictions are now ahead of their 2025 phosphorus targets, virtually all of the remaining phosphorus reductions will have to come from Pennsylvania.

Virginia is in a better position with respect to both nitrogen and phosphorus under the phase 6 model. Virginia's nitrogen gap has decreased from 3.3 million pounds (6 percent of 2017 loads) to 2.4 million pounds (4 percent of 2017 total). Virginia's phosphorus gap, which was very small in the phase 5.3.2 model, has disappeared, and Virginia is now meeting its 2025 phosphorus target.

West Virginia, which was already close to meeting its 2025 targets in the phase 5.3.2 model, is now meeting the targets for both nitrogen and phosphorus.

Table 5: NITROGEN – delivered loads by jurisdiction (millions of pounds)

	2017 load		2025 target[15]		Gap		Gap / 2017 load		State gap / total gap[16]	
	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6
Delaware	4.1	6.5	3.4	4.6	0.7	1.9	18%	30%	2%	4%
D.C.	1.6	1.5	2.4	2.4						
Maryland	46.9	54.2	41.2	45.8	5.7	8.4	12%	16%	13%	17%
New York	10.9	14.3	8.8	11.5	2.0	2.8	19%	19%	5%	6%
Pennsylvania	111.0	107.3	79.0	73.2	32.0	34.1	29%	32%	73%	69%
Virginia	55.9	58.2	52.6	55.7	3.3	2.4	6%	4%	8%	5%
West Virginia	5.1	7.8	5.0	8.2	0.1		1%		0%	
TOTAL	*235.5*	*249.8*	*192.4*	*201.4*	*43.1*	*48.4*	*18%*	*19%*		

Table 6: PHOSPHORUS – delivered loads by jurisdiction (millions of pounds)

	2017 load		2025 target[17]		Gap		Gap / 2017 load		State gap / total gap[18]	
	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6
Delaware	0.27	0.12	0.28	0.11		0.01		9%		1%
D.C.	0.07	0.08	0.12	0.13						
Maryland	2.72	3.67	2.81	3.68						
New York	0.75	0.63	0.64	0.59	0.11	0.05	14%	7%	13%	6%
Pennsylvania	4.20	3.80	3.57	3.04	0.63	0.76	15%	20%	80%	93%
Virginia	6.43	6.12	6.40	6.19	0.03		0%		4%	
West Virginia	0.65	0.43	0.63	0.43	0.02		3%		2%	
TOTAL	15.10	14.84	14.46	14.17	0.64	0.67	4%	5%		

[15] 2025 targets under the Phase 5.3.2 model were obtained from the Chesapeake Bay TMDL Tracker website, and appear to represent Phase II WIP planning targets.

[16] The "total gap" used as a denominator here is the total number of pounds yet to be reduced by jurisdictions that are still discharging more than their 2025 targets. In other words, we assume that overperformance in one jurisdiction (e.g., Washington D.C., which is already discharging less than 2025 targets) will not excuse underperformance in other jurisdictions, and that all jurisdictions will be expected to meet their targets.

[17] See supra note 14.

[18] See supra note 15.

Table 7: SEDIMENT – delivered loads by jurisdiction (millions of pounds)

	2017 load		2025 target[19]		Gap		Gap / 2017 load		State gap / total gap[20]	
	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6	Phase 5.3.2	Phase 6
Delaware	81	26	100							
D.C.	16	40	17							
Maryland	1,185	7,575	1,350	7,328		247		3%		
New York	322	666	304		17		5%			
Pennsylvania	2,377	2,934	1,945		432		18%			
Virginia	3,475	6,455	3,251		224		6%			
West Virginia	331	556	373							
TOTAL	7,787	18,253	7,341		447		6%			

[19] See supra note 14.
[20] See supra note 15.

c. Trajectories

Another way to look at the jurisdictions is to compare their rates of change over the past eight years (or between 2009 and 2017) to the rates of change that will be required to meet the 2025 targets. **Tables 8 through 10** summarize these estimates, and show that each jurisdiction is in a different place:

- **Delaware** will have to roughly double its rate of nitrogen load reduction, and this is true using either model. The phase 6 model shows that Delaware still has to make additional phosphorus reductions, but at its current rate the state is on-track to meet its target ahead of time.

- **Washington, D.C.** is already below the 2025 targets for nitrogen and phosphorus.

- In the phase 5.3.2 model, **Maryland** was close to being on a trajectory for meeting its nitrogen target. This is no longer the case. Now Maryland will have to triple its rate of nitrogen reductions from 0.7 percent per year to 2.1 percent per year. Both models show that Maryland is already meeting 2025 phosphorus targets.

- Both models show that **New York** will have to greatly accelerate its pace of nitrogen reductions. For phosphorus, both models suggest that New York is on-track to meet the 2025 target ahead of schedule.

- In the phase 5.3.2 model, **Pennsylvania** was dramatically off-track for meeting its nitrogen target. In the phase 6 model, Pennsylvania is still off-track, but by a lesser degree. The new model suggests that Pennsylvania will have to achieve a six-fold increase in the rate of nitrogen reductions, from 0.8 percent per year to 4.7 percent per year. Pennsylvania is also the only jurisdiction not meeting or on track to meet its 2025 phosphorus target. The current rate of phosphorus reductions will have to be modestly accelerated, from 2.1 percent per year to 2.8 percent per year.

- **Virginia** is in good shape. Specifically, Virginia is on-track to meet its 2025 nitrogen target ahead of time in both models, and is already meeting its 2025 phosphorus target in the phase 6 model.

- The phase 5.3.2 model showed **West Virginia** making nitrogen and phosphorus reductions at rates that would get the state to its 2025 targets early. The phase 6 model shows that the state is already meeting both 2025 targets.

Table 8: Rates of change in delivered nitrogen load (% per year)[21]

	Phase 5.3.2		Phase 6	
	2009-2017	2017-2025	2009-2017	2017-2025
Delaware	-1.2%	-2.5%	-2.5%	-4.3%
D.C.	-8.0%	(below target)	-7.7%	(below target)
Maryland	-1.3%	-1.6%	-0.7%	-2.1%
New York	+0.5%	-2.6%	-0.4%	-2.7%
Pennsylvania	-0.2%	-4.2%	-0.8%	-4.7%
Virginia	-2.5%	-0.8%	-1.9%	-0.5%
West Virginia	-0.8%	-0.2%	-0.5%	(below target)
TOTAL	*-1.1%*	-2.5%	*-1.1%*	-2.7%

Table 9: Rates of change in delivered phosphorus load (% per year)

	Phase 5.3.2		Phase 6	
	2009-2017	2017-2025	2009-2017	2017-2025
Delaware	-3.7%	(below target)	-3.6%	-1.1%
D.C.	-0.1%	(below target)	+0.4%	(below target)
Maryland	-2.6%	(below target)	-1.1%	(below target)
New York	-3.3%	-1.9%	-2.6%	-0.9%
Pennsylvania	-2.2%	-2.0%	-2.1%	-2.8%
Virginia	-4.6%	-0.1%	-1.4%	(below target)
West Virginia	-4.4%	-0.4%	-4.9%	(below target)
TOTAL	*-3.5%*	*-0.5%*	*-1.7%*	*-0.6%*

Table 10: Rates of change in delivered sediment load (% per year)

	Phase 5.3.2		Phase 6	
	2009-2017	2017-2025	2009-2017	2017-2025
Delaware	-2.9%	(below target)	-10.4%	
D.C.	-1.9%	(below target)	+0.4%	
Maryland	-2.1%	(below target)	-0.1%	-0.4%
New York	-0.0%	-0.7%	-0.8%	
Pennsylvania	-0.8%	-2.5%	-1.5%	
Virginia	-0.9%	-0.8%	-0.2%	
West Virginia	-4.1%	(below target)	-1.0%	
TOTAL	*-1.2%*	*-0.7%*	*-0.4%*	

[21] Rates of change between 2009 and 2017 were calculated as the slope of the linear regression through annual load divided by the average 2009-2017 load. The implied rate of change between 2017 and 2025 was calculated as one-eighth of the difference between the 2025 target and the 2017 load divided by the average of the 2017 and 2025 loads.

IV. Sources of Nutrients and Sediment

Nutrients and sediment in the Chesapeake Bay come from various sources that include agricultural land, developed land, natural land (forests and wetlands, for example), and atmospheric deposition. The phase 5.3.2 and phase 6 models use slightly different categories and nomenclature, but can be compared across several broad groups of sources. Tables 12 through 14 show 2017 delivered load for each pollutant. The phase 6 model includes a broad "natural" sector that includes a variety of sources including forest, non-tidal water deposition, open space, shoreline erosion, streams, and wetlands. For clarity, the natural sector is broken out into these component sources below. It is important to note that coastal erosion is a new source in the phase 6 model, not quantified in earlier models. For that reason, Tables 12 through 14 include a subtotal that excludes coastal erosion. The "stream" *category* is also new in phase 6, but the loads are not. The nutrients and sediments now being attributed to "streams" were formerly attributed to various land use categories. And, in fact, much of the "stream" load represents nutrients and sediment coming from upstream land uses, temporarily depositing in streambeds and streambanks, and then re-suspending into the water column and travelling to the Bay.

Tables 11 through 13 show that the phase 6 model apportions nitrogen in roughly the same way as the phase 5.3.2 model: Roughly half of the delivered nitrogen comes from agriculture, 15-20 percent comes from urban stormwater, and 14 percent comes from wastewater point sources.

For phosphorus, the phase 6 model places a significant portion of the total load (20 percent) in the "stream" category. This load would have been attributed to upstream land uses in the phase 5.3.2 model. The agricultural phosphorus load is less than half of what it was in phase 5.3.2. This is true for both delivered loads (Table 13) and edge-of-stream loads (data not shown). This suggests that the difference is due to changes in how the model simulates the release of phosphorus from land, not changes in how the model simulates the transport of phosphorus in streams. Stormwater and wastewater loads are roughly the same in phase 6 as they were in phase 5.3.2, but as a fraction of total load they are now equal to or greater than what they were in phase 5.3.2. Specifically, stormwater phosphorus in phase 6 represents 20 percent of the non-shoreline load (Table 13), and 18 percent of the total load. This category was assigned 18 percent of the total phosphorus load in phase 5.3.2. Wastewater point sources now represent 17 percent of the non-shoreline load and 15 percent of the total load, where they were assigned 14 percent of the total load in phase 5.3.2.

Sediment loads are quite different in phase 6, with half of the total load coming from shoreline erosion, and the majority of non-shoreline sediment now attributed to "streams." Again, this 'stream' load would have been attributed to upstream land uses in the phase 5.3.2 model. As with phosphorus, the agricultural sediment load in phase 6 is less than half of what it was in phase 5.3.2. Stormwater sediment loads are slightly lower in phase 6, and represent a smaller slice of the pie than they did in phase 5.3.2.

Although much of the phosphorus and sediment load is now modeled as coming from streams, it is important to remember that reducing the 'stream' load can be accomplished in two ways – through stream restoration and through reducing the upstream sources of phosphorus and sediment. This means that the Bay states should continue to pursue strategies for reducing phosphorus and sediment from agriculture, stormwater and (for phosphorus) wastewater, even if those sources now appear to be smaller slices of the pie.

Table 11: 2017 delivered nitrogen loads (millions of pounds)

	Phase 5.3.2	% of non-shoreline total	Phase 6	% of non-shoreline total
Agricultural land	106.3	45%	120.1	49%
Developed land[22]	41.3	18%	39.6	16%
Wastewater point sources[23]	32.0	14%	35.1	14%
Forest, Open Space, and Wetlands[24]	43.2	18%	24.5	10%
Non-tidal water deposition	2.4	1%	4.6	2%
Septic	8.7	4%	7.8	3%
Combined Sewer Overflows	1.4	1%	1.5	1%
Streams (new in phase 6)			14.0	6%
Subtotal	235.5		247.1	
Shoreline erosion (new in phase 6)			2.7	
Total	235.5		249.8	

[22] These values come from the "developed" sector in the phase 6 model, and from the "stormwater" or "urban" sector in the phase 5.3.2 model.
[23] These values come from the "wastewater" source in phase 6, and the "point source" category (industrial and wastewater treatment plants) in phase 5.3.2.
[24] The phase 5.3.2 "forest" category included lands that are now classified separately as wetlands or open space. So the values in this row come from the "forest," "open space," and "wetlands" sources in phase 6, and from the "forest" category in phase 5.3.2.

Table 12: 2017 delivered phosphorus loads (millions of pounds)

	Phase 5.3.2	% of non-shoreline total	Phase 6	% of non-shoreline total
Agricultural land	8.4	56%	4.1	32%
Developed land[25]	2.7	18%	2.6	20%
Wastewater point sources[26]	2.1	14%	2.2	17%
Forest, Open Space, and Wetlands[27]	1.5	10%	0.9	7%
Non-tidal water deposition	0.1	1%	0.3	2%
Septic	0	<1%	0.002	<1%
Combined Sewer Overflows	0.2	1%	0.2	1%
Streams (new in phase 6)			2.6	20%
Subtotal	15.1		13.0	
Shoreline erosion (new in phase 6)			1.9	
Total	15.1		14.8	

[25] These values come from the "developed" sector in the phase 6 model, and from the "stormwater" or "urban" sector in the phase 5.3.2 model.
[26] These values come from the "wastewater" source in phase 6, and the "point source" category (industrial and wastewater treatment plants) in phase 5.3.2.
[27] The phase 5.3.2 "forest" category included lands that are now classified separately as wetlands or open space. So the values in this row come from the "forest," "open space," and "wetlands" sources in phase 6, and from the "forest" category in phase 5.3.2.

Table 13: 2017 delivered sediment loads (millions of pounds)

	Phase 5.3.2	% of non-shoreline total	Phase 6	% of non-shoreline total
Agricultural land	4,576	59%	1,660	18%
Developed land[28]	1,915	25%	1,697	19%
Wastewater point sources[29]	63	<1%	63	<1%
Forest, Open Space, and Wetlands[30]	1,241	16%	674	7%
Non-tidal water deposition	0		0	
Septic	0		0	
Combined Sewer Overflows	19	<1%	19	<1%
Streams (new in phase 6)			5,033	55%
Subtotal	7,787		9,107	
Shoreline erosion (new in phase 6)			9,145	
Total	7,787		18,253	

[28] These values come from the "developed" sector in the phase 6 model, and from the "stormwater" or "urban" sector in the phase 5.3.2 model.

[29] These values come from the "wastewater" source in phase 6, and the "point source" category (industrial and wastewater treatment plants) in phase 5.3.2.

[30] The phase 5 "forest" category included lands that are now classified separately as wetlands or open space. So the values in this row come from the "forest," "open space," and "wetlands" sources in phase 6, and from the "forest" category in phase 5.3.2.

Table 14: Trends in agricultural nitrogen load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2	Annual change, 2009-2017 Phase 6
Delaware	-1.6%	-3.1%
Maryland	-1.5%	-0.5%
New York	-0.4%	-1.5%
Pennsylvania	+0.7%	-0.1%
Virginia	-2.7%	-0.5%
West Virginia	-1.2%	-0.8%
TOTAL	-0.4%	-0.5%

Table 15: Trends in agricultural phosphorus load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2	Annual change, 2009-2017 Phase 6
Delaware	-4.2%	-7.0%
Maryland	-2.2%	-1.5%
New York	-3.3%	-1.8%
Pennsylvania	-1.0%	-1.4%
Virginia	-5.9%	-0.6%
West Virginia	-3.3%	-2.4%
TOTAL	-3.7%	-1.2%

Table 16: Trends in agricultural sediment load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2	Annual change, 2009-2017 Phase 6
Delaware	-3.8%	-13.1%
Maryland	-3.1%	-2.2%
New York	-0.1%	-1.8%
Pennsylvania	-0.9%	-2.6%
Virginia	-1.1%	-1.8%
West Virginia	-3.1%	-3.3%
TOTAL	-1.4%	-2.3%

Table 17: Trends in developed/stormwater nitrogen load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2 ("stormwater")	Annual change, 2009-2017 Phase 6 ("developed")
D.C.	-0.4%	-1.0%
Delaware	+1.7%	+0.7%
Maryland	+0.5%	+0.4%
New York	+0.3%	+0.3%
Pennsylvania	+0.0%	+0.5%
Virginia	+1.5%	+0.9%
West Virginia	+0.2%	-0.4%
TOTAL	+0.5%	+0.6%

Table 18: Trends in developed/stormwater phosphorus load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2 ("stormwater")	Annual change, 2009-2017 Phase 6 ("developed")
D.C.	-2.7%	-1.9%
Delaware	-0.9%	+0.7%
Maryland	-1.5%	-0.2%
New York	-1.8%	-0.3%
Pennsylvania	-1.7%	+0.2%
Virginia	-1.3%	+1.0%
West Virginia	-7.8%	-3.1%
TOTAL	-1.7%	+0.4%

Table 19: Trends in developed/stormwater sediment load (delivered) among the Bay states

	Annual change, 2009-2017 Phase 5.3.2 ("stormwater")	Annual change, 2009-2017 Phase 6 ("developed")
D.C.	-2.0%	-2.4%
Delaware	-1.5%	+0.6%
Maryland	-1.3%	+0.6%
New York	-0.1%	-0.9%
Pennsylvania	-1.0%	-0.8%
Virginia	+0.3%	+0.8%
West Virginia	-10.4%	+0.1%
TOTAL	-0.9%	+0.1%