Murky Waters

More Accountability Needed for Agricultural Pollution in the Chesapeake Bay

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ENVIRONMENTAL INTEGRITY PROJECT

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Executive Summary

The Chesapeake Bay Total Maximum Daily Load (TMDL), a multistate, multi-year effort to restore the health of the Bay through pollution limits, is several years along with little evidence of progress. Many indicators of Bay health are not improving, and although some pollution source sectors have made demonstrable progress, overall pollution loads are not declining nearly fast enough.

The Bay TMDL will only succeed if every source of nutrient pollution is accountable. The agricultural sector – including crop farms, livestock farms, and concentrated animal feeding operations – contributes more of the pollutants that impair Bay health than any other sector. In 2013, agriculture was responsible for 42% of nitrogen pollution, 57% of phosphorus, and 59% of sediment delivered to the Bay. Agricultural sources pollute in multiple ways, but the dominant pathways are runoff and groundwater infiltration from fields fertilized with manure or commercial fertilizers. This pollution is not easy to trace, because it does not flow out of a pipe like conventional "point sources." Point sources are routinely monitored, so we know what the baseline amounts of pollution from these sources were before the Bay TMDL was created in 2010, and we know how much TMDL-related efforts have reduced the pollution. With most agricultural sources, however, the baseline amounts of pollution and future reductions are based on modeling and educated guesses. Since agricultural reductions are essential to the success of the TMDL, the assumptions built into these models are critically important. If the assumptions are wrong, the model predictions are also wrong. The data we review in this report suggest that the assumptions and the models may be overestimating the reductions in agricultural pollution.

One of the central recommendations of this report is that the Bay states need better monitoring in small sub-watersheds dominated by agricultural land use. The best way to ensure that the agricultural sector is accountable for its pollution is to use the same tools that we apply to regulated point sources – routine monitoring data. Although nonpoint sources like agriculture are clearly more difficult to monitor, and comprehensive monitoring on a farm-by-farm basis is prohibitively expensive, there are many ways to evaluate water quality on an aggregate scale. The Chesapeake Bay Program partnership has been working to develop this kind of targeted monitoring strategy, as discussed in more detail in this report, and we offer another specific research design that would generate the kind of information that could help explain the apparent disconnect between modeled agricultural loads and overall TMDL progress.

This report also focuses on a key set of assumptions about agricultural Best Management Practices, or BMPs, which are the main tools used by crop farms, livestock farms, and concentrated animal feeding operations to manage nutrient and sediment pollution. These management practices include things like cover crops, streamside forest buffers, and other strategies that help prevent nitrogen and phosphorus pollution from leaving farm fields and entering surface water. The model being used by the Bay states assumes that each BMP will achieve specific pollution reductions. These "effectiveness estimates" (or "efficiencies") are used in overall planning efforts, and they are also used in specific policy initiatives. Agricultural policies, like the Bay model predictions for agriculture, are only as good as the BMP assumptions that they rely on. It is essential to the success of the TMDL that the Bay states know how well BMPs work in the field.

Unfortunately, there is a large knowledge gap when it comes to agricultural BMPs. Assumptions about their effectiveness are based on small-scale, carefully controlled experiments. Research into real-world BMP implementation at the larger and more meaningful watershed scale suggests that the BMPs may not be working as well as policymakers hoped. We know that BMPs are being adopted across the watershed, and the management practices are undoubtedly achieving some degree of pollution reduction. But so far there is little evidence of corresponding improvements in water quality. In this report we review research that has started to characterize the effects of certain BMPs on water quality. We also review the most important gaps in current research.

This report concludes with the following recommendations:

- The amounts of nitrogen and phosphorus being applied in fertilizer on farms are increasing, according to some evidence discussed in this report. Farmers should more carefully manage these manure and chemical fertilizers, and reduce them in areas where excessive amounts are being applied.

- The Bay states will need better monitoring data in small sub-watersheds dominated by agriculture to accurately track pollution from farms.

- In order to build confidence in agricultural BMPs, we need better information on their performance. This includes, for example, monitoring data showing how well these management practices perform in the field during storms, which are responsible for the majority of phosphorus loads. Appendix C to this report proposes a monitoring study that would accomplish this goal.

- The Bay states must make better use of existing information to track agricultural progress. States are now capable of predicting nitrogen and phosphorus pollution from individual fields based on site-specific soil, land use, crop planting, and fertilizer application data. These predictions, if made for all of the fields in a small watershed, could be directly compared to water quality monitoring data for that watershed. This is a project that the states should be pursuing, and the states should also be sharing the relevant land-use information with the public to maximize the opportunities for cross-checks between water quality monitoring and model predictions.

- In the meantime, there will continue to be substantial uncertainty around BMP effectiveness. In addition, there is ongoing uncertainty around the degree to which BMPs are implemented and maintained. Until this uncertainty is significantly reduced, it is unwise to rely on assumptions about BMP effectiveness without some margin of safety. For instance, the EPA expects the Bay states to use a 2:1 "uncertainty ratio" in pollution credit trades between point and nonpoint sources. This means that a point source hoping to offset one pound of nitrogen must purchase two pounds of nitrogen credits from a farm or other nonpoint source. Virginia is already using such a ratio in its pollution trading program. The rest of the Bay states must follow suit, and must also apply a similar margin of safety in other programs that rely on agricultural BMPs to achieve pollution reductions. Without this margin of safety, there is a high likelihood that pollution reduction goals of the Chesapeake Bay TMDL will not be met.

1. Introduction

1.1 The Chesapeake Bay TMDL

The Chesapeake Bay has been unable to adequately support aquatic life for decades. In 2010, after repeated attempts to restore the Bay's health came up short, the U.S. EPA and the Bay states (including Washington, D.C.) established a Total Maximum Daily Load (TMDL), or "pollution diet," for the Bay.[1] The executive summary of the TMDL succinctly described the problem:

> Most of the Chesapeake Bay and its tidal waters are listed as impaired because of excess nitrogen, phosphorus, and sediment. These pollutants cause algal 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 reduction 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 water quality goals for the Chesapeake Bay and its tidal waters.[2]

The TMDL development process was complicated, with many interlocking pieces. To begin with, the Chesapeake Bay watershed covers parts of six states and the District of Columbia. In order to capture environmental and political subdivisions, the TMDL is based on 92 Bay waterbody segments.[3]

The need for the TMDL was formally established by demonstrating that water quality exceeded state water quality standards.[4] Specifically, in 2008, 89 of the 92 segments were listed as impaired because they failed to meet state water quality standards for dissolved oxygen, submerged aquatic vegetation, nutrient indicators, and/or indicators of eutrophication (algal blooms).[5] Under the TMDL, each segment is expected to meet one or more "designated uses" for aquatic life.[6] In order to define the target water quality that the TMDL would attempt to achieve, the EPA and the states derived three sets of criteria (for dissolved oxygen, chlorophyll a, and water clarity) that vary by segment and by designated use.[7]

After defining water quality goals, the TMDL used a set of simulation models to estimate the pollution load reductions necessary to achieve target water quality conditions for all criteria in all segments.[8] These models are not fixed in place; instead, the Chesapeake Bay Program periodically updates the models to reflect new information. The current Watershed Model, version 5.3, represents a substantial improvement over the previous version by incorporating 296 monitoring stations, modeling over 2,000 river segments and 25 land use types, and running over a 20-year period.[9] Model outputs are used by the EPA and the states to allocate the allowable loads among the jurisdictions and among point and non-point sources.[10] Finally, each state demonstrates how it will meet its allocations through a Watershed Implementation Plan (WIP).[11]

While the development and implementation of the TMDL has been complex, it is helpful to remember that the TMDL is, at its core, relatively straightforward: The TMDL limits three pollutants – nitrogen, phosphorus, and sediment – in order to meet three benchmarks of water quality – dissolved oxygen, chlorophyll a, and water clarity.

1.2 Agriculture

When the 2010 TMDL was published, agriculture was estimated to be the largest source of all three pollutants, responsible for 44% of the nitrogen loads, 44% of the phosphorus loads, and 65% of the sediment loads delivered to the Bay.[12] These numbers have changed slightly since then due to changes in the underlying models and changes in loadings; among other things, agriculture is now divided into sources that are not federally regulated (nonpoint-source loads from farmland) and sources that are federally regulated (CAFOs). These changes have not affected the overall picture, however – agriculture continues to represent the largest source of nitrogen, phosphorus, and sediment loads delivered to the Bay. As shown in **Table 1**, agriculture was estimated to contribute 42% of total nitrogen loads, 57% of total phosphorus loads, and 59% of total sediment loads delivered to the Bay in 2012.

Table 1: Estimated loads of nitrogen, phosphorus, and sediment (total suspended solids) delivered to the Chesapeake Bay in 2009 and 2013 (pounds per year).[13]

Nitrogen	2009	% of total	2013	% of total
Agriculture	111,935,006	40%	105,577,495	41%
Agriculture-Regulated	1,863,037	1%	1,799,000	1%
Forest	43,738,302	16%	43,397,405	17%
Non-Tidal Water Deposition	2,416,872	1%	2,417,781	1%
Onsite	8,418,099	3%	8,750,950	3%
Regulated Stormwater	21,793,450	8%	23,570,864	9%
Urban	17,902,710	6%	17,186,641	7%
Wastewater	50,586,224	18%	39,468,658	15%
Wastewater-CSO	1,593,197	1%	1,415,441	1%
Tidal deposition	19,370,000	7%	16,900,000	6%
Total	279,618,906	100%	260,486,248	100%
Phosphorus	**2009**	**% of total**	**2013**	**% of total**
Agriculture	10,131,246	53%	9,522,324	55%
Agriculture-Regulated	414,784	2%	361,896	2%
Forest	1,556,046	8%	1,539,844	9%
Non-Tidal Water Deposition	144,652	1%	144,569	1%
Onsite	-	0%	-	0%
Regulated Stormwater	1,452,419	8%	1,416,025	8%
Urban	1,557,446	8%	1,395,794	8%
Wastewater	3,790,671	20%	2,649,084	15%
Wastewater-CSO	181,629	1%	159,634	1%
Tidal deposition	-	0%	-	0%
Total	19,228,893	100%	17,189,171	100%
Total Suspended Solids	**2009**	**% of total**	**2013**	**% of total**
Agriculture	5,287,318,908	61%	4,792,865,802	59%
Agriculture-Regulated	8,122,782	0%	6,999,641	0%
Forest	1,273,800,000	15%	1,257,918,009	15%
Non-Tidal Water Deposition	-	0%	-	0%
Onsite	-	0%	-	0%
Regulated Stormwater	953,250,815	11%	1,006,423,000	12%
Urban	1,065,660,333	12%	1,027,552,562	13%
Wastewater	64,806,707	1%	67,227,754	1%
Wastewater-CSO	22,292,254	0%	18,789,723	0%
Tidal deposition		0%		0%
Total	8,675,251,798	100%	8,177,776,491	100%

2. TMDL progress

Although this report is focused on agricultural loads, it is important to start with the broader context, and a simple question: Is the health of the Chesapeake Bay improving? Based on the structure of the TMDL and its implementation, there are several metrics for measuring TMDL progress. These fall into three broad categories: (1) measurable indicators of ecological health, including the water quality criteria that drive the TMDL model, (2) estimates of nutrient and sediment loadings, and (3) statistics describing the implementation of pollution reduction strategies. Progress measured by the various metrics is described below. This section focuses on overall trends; trends within the agricultural sector are discussed in the following section.

Note that for each metric there may be multiple tracking tools and ways of measuring progress. We focus here on the database and tracking tools maintained by the U.S. EPA Chesapeake Bay Program.[14] We also refer to the University of Maryland Center for Environmental Science (UMCES), which maintains an alternative set of tracking tools under the heading of their Chesapeake Bay Report Card.[15] The trends in UMCES scores sometimes diverge from the trends in Bay Program results, so it is important to note that "[t]he Chesapeake Bay report card is not a TMDL tracking tool."[16]

Overall, despite significant progress in implementation, and measurable reductions in some waste streams, the health of the Chesapeake Bay does not appear to be improving.

2.1 Pollution loads and related metrics

The Chesapeake Bay Program reports pollution loadings in two ways. First, they report loads for each year based on a combination of water monitoring and simulation modeling.[17] For nitrogen and phosphorus, inputs include monitoring data collected from River Input Monitoring (RIM) sites, which characterize loads from the majority of the watershed, monitoring data from wastewater treatment facilities downstream of the RIM site, and computer modeling estimates for nonpoint sources downstream of the RIM sites. For sediment, the indicator only captures loadings from upstream of the RIM sites. We refer to this indicator below as "Annual Load."

The second Bay Program indicator models pollution loads using the phase 5.3.2 Watershed Model and long-term average weather data, with estimates for 1985, 2009, and 2013. As stated by the Bay Program, "[t]his simulation does not represent how much nitrogen actually reached the Bay in [a given year] since the loads from agriculture, urban runoff, septic, forest and atmospheric sources are based on long-term average hydrology rather than the actual amount of water flowing into the Bay."[18] We refer to this indicator below as "Modeled Load." For sediment, this indicator estimates total loadings for the watershed, up- and downstream of the

RIM sites, and therefore predicts greater sediment loads than the annual load indicator described above.[19]

The Bay Program shows modeled loads next to targets for 2017 and 2025. It should be noted that the 2025 targets are higher than the TMDL allocations for each pollutant.[20] The Bay Program states that "[t]hese planning targets, while slightly higher than the allocations published in the December 2010 TMDL, represent the actions, assumptions, and 'level of effort' necessary to meet the TMDL allocations."[21]

In addition to these indicators, UMCES reports nitrogen and phosphorus "scores" based on how often Bay-wide concentrations of nitrogen and phosphorus in surface water fall below "reference community thresholds." While these scores are not estimates of pollutant loads, we mention them in this section, and present the data in Appendix A, for comparison of general trends.

2.1.1 Nitrogen

Figure 1 shows annual nitrogen loads, modeled nitrogen loads for 1985, 2009, and 2013, and the 2025 TMDL target load for nitrogen (207.27 million pounds). Although there is a long-term downward trend in annual loads, if loads continue to decline at the average rate, loads in 2025 will still be significantly higher than the target, as shown by the annual load trend line in **Figure 1**. Consistent with the trend for annual loads, the UMCES nitrogen score for the Bay has been gradually improving, as shown in **Figure A-8**.[22]

2.1.2 Phosphorus

Figure 2 shows annual phosphorus loads, modeled phosphorus loads for 1985, 2009, and 2013, and the 2025 TMDL target load for phosphorus (14.55 million pounds). Although modeled loads are declining, actual loads are increasing, with 2011 having the highest load to the Bay since 1990. The trend for the UMCES phosphorus score diverges from the trend for phosphorus loads. Although phosphorus loads are increasing, the UMCES phosphorus score is gradually improving (See **Figure A-9**).[23]

Figure 1: Nitrogen loads to the Chesapeake Bay

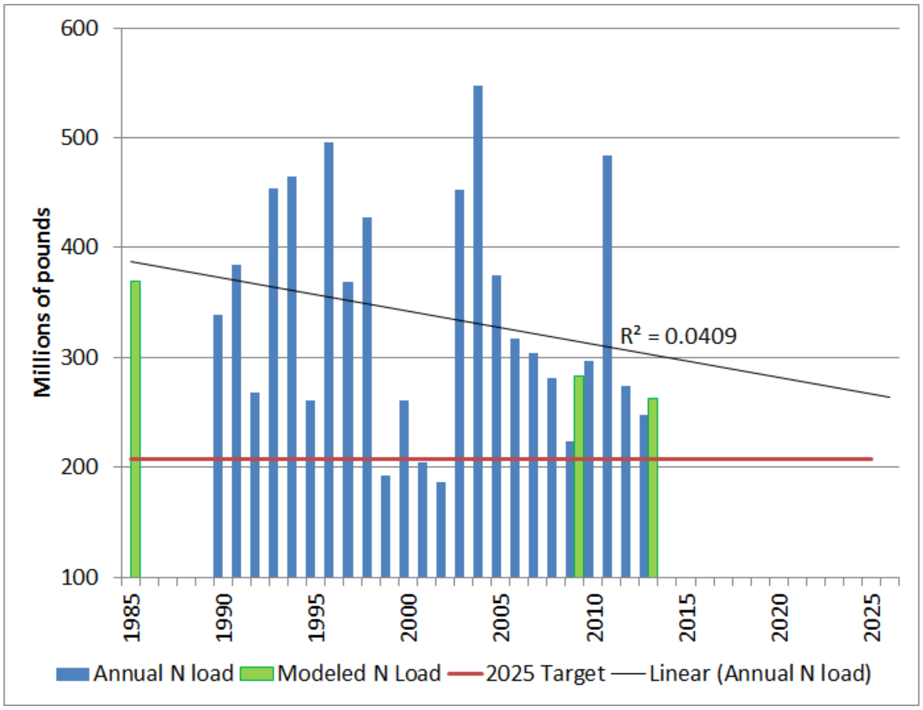
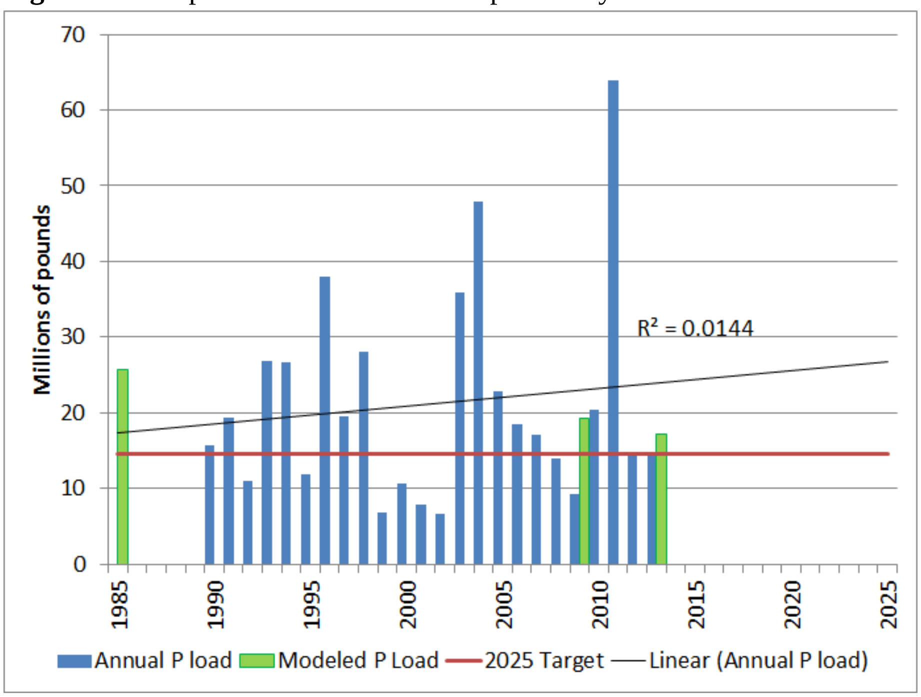


Figure 2: Phosphorus loads to the Chesapeake Bay

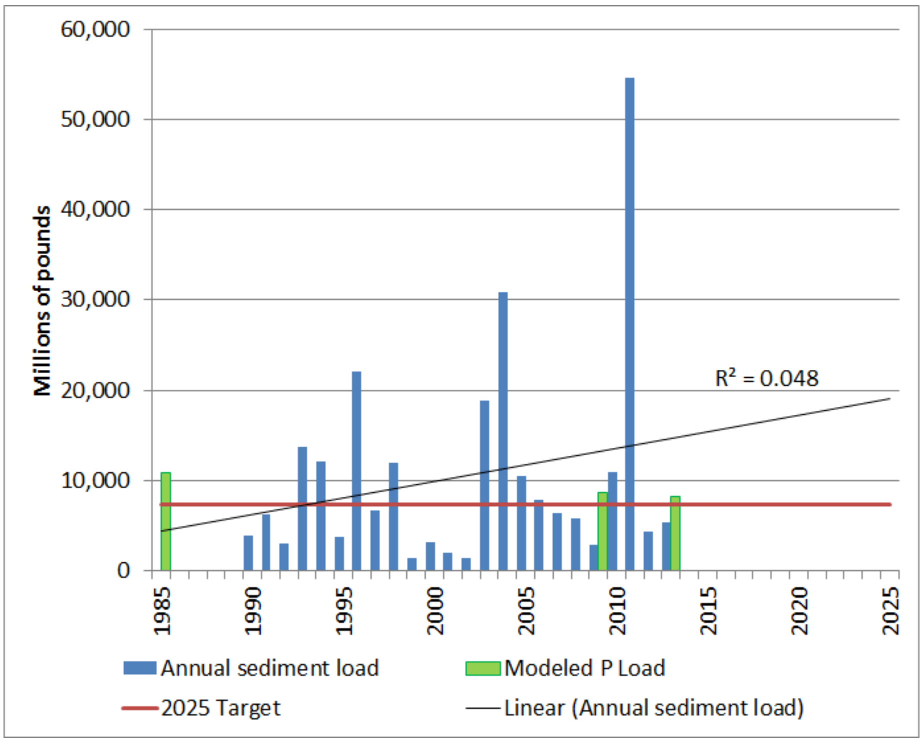


2.1.3 Sediment

The Bay Program tracks sediment loads with two different metrics. The first, computed and reported on an annual basis, only estimates sediment loads from areas upstream of the RIM sites. According to this metric, sediment loads have been increasing, with 2011 having the highest load since before 1990. The Bay Program also models loads for the entire watershed, and has estimated loads for 1986, 2009, and 2013. According to this metric, modeled sediment loads have been declining.

Although the two sediment estimates are not directly comparable, we plot them together in **Figure 3**. Note that annual loads, which only account for a part of the Bay watershed, routinely exceed modeled loads for the entire watershed. The upward trend in annual loads suggests that consistently meeting the 2025 target will be difficult.

Figure 3. Sediment loads to the Bay.



2.1.4. USGS load estimates

The U.S. Geological Survey (USGS) estimates the loads of nitrogen, phosphorus, and sediment entering the Chesapeake Bay each year using regression models.[24] There are two reasons why we chose to focus on the Bay Program annual load estimates rather than the USGS estimates. First, the USGS models only assess loads at the RIM sites, meaning that 22% of the watershed is not accounted for.[25] Second, the USGS model estimates are flow-adjusted or flow-normalized "to remove the variability in water quality conditions that is directly related to the random variations in discharge [flow]."[26] We chose to focus on load estimates that are not flow-adjusted because load reductions will have to be achieved regardless of flow. In addition, it is important to consider the likelihood that variations in discharge flow are not random, and that high-intensity precipitation events are increasing.[27]

Despite these differences, the USGS results are consistent with the results presented above. Overall, the USGS models show decreasing nitrogen loads and increasing phosphorus and sediment loads since 1985.[28] For nitrogen, the USGS reports that long-term declines have slowed over the last decade:

> [F]low-normalized trends in total nitrogen yield at eight of the nine RIM stations show that the rate of improvement has either slowed (three of eight RIMS stations), changed from improving to degrading (three of eight RIMS stations), or the rate of degradation has accelerated (two of the eight RIM stations).[29]

As with nitrogen, phosphorus trends have also been getting worse in recent years: "[T]he rate of total phosphorus delivery is increasing (degrading conditions) and this rate of total phosphorus delivery is further increasing at eight of the nine RIM stations for the more recent 2001-2010 period."[30] The USGS only assessed long-term sediment load trends for four of the nine RIM stations, and two showed declines, while the other two (including the Susquehanna station) showed increases.[31] Over the last ten years, "eight of the nine RIM stations exhibit patterns of increasing yields; although there is considerable variation, sediment yield is generally on the rise at these stations."[32]

2.2 Indicators of Ecological Health

The Bay Program and UMCES evaluate ecological health with water quality and species abundance measures. Although some indicators show a slight uptick over the past 25 years (water clarity attainment as measured by the Chesapeake Bay Program), the majority of indicators are flat (e.g., dissolved oxygen in the deep water and deep channels) or declining (e.g., chlorophyll *a* indicators).

2.2.1 Dissolved Oxygen

The Chesapeake Bay program reports dissolved oxygen results in terms of attainment of the dissolved oxygen criteria. Progress toward attainment varies by designated use, as shown in Appendix A, **Figure A-1**. Attainment of dissolved oxygen criteria in open water, which applies to all 92 Bay segments, has been gradually increasing over the long term, but decreasing over the past 10-15 years to 55% attainment in the most recent data. Attainment in deep water has been essentially flat at 20-40%. Attainment in the deep channel is currently 0%, and has never exceeded 20%. Attainment for the migratory fish and spawning nursery use (73 segments) has been steadily declining over the long term.

The attainment assessments cited immediately above use a surface area-weighted approach to synthesizing results across multiple segments. An alternative volume-weighted approach produces a pattern similar to that for open water areas, with a slight increase in attainment over the long term, but a decline over the past 10-15 years. Current attainment under the volume-weighted approach is roughly 35%.[33]

The UMCES results for dissolved oxygen are very different from the Chesapeake Bay Program results. Where the Chesapeake Bay Program reports 0-60% attainment of dissolved oxygen standards in 2010-2012, UMCES reports 77-86% scores over the same period, with the scores reflecting "how often (% of sampling times) dissolved oxygen levels were above or below the threshold between June and September."[34] Since 1986, UMCES results for dissolved oxygen show a slight improvement from scores of roughly 80% in 1986-88.

In short, the Bay has seen little or no progress toward the 100% attainment goal for dissolved oxygen.

2.2.2 Chlorophyll *a*

The Chesapeake Bay Program only tracks chlorophyll *a* attainment for the segments with applicable chlorophyll *a* standards – mainstem James River segments in Virginia and the Potomac and Anacostia segments in the District of Columbia.[35] Attainment for these segments is currently 0%. Over the past 30 years, and on a surface area-weighted basis, attainment for these segments has been as high as 49% (in 2000-02), but is usually below 5%.

UMCES tracks chlorophyll a Bay-wide, with a scoring system that measures the percentage of each growing season (March – September) that a given estuary is below certain threshold concentrations.[36] According to this scoring system, chlorophyll *a* attainment has been declining steadily since 1986 (**Figure A-2**).

UMCES also reports that "[t]he James River had the best chlorophyll *a* score of all the regions" in 2012.[37] This is hard to reconcile with the Chesapeake Bay Program's conclusion that the James River main stem had 0% attainment of chlorophyll *a* standards in 2010-2012, and highlights the fact that TMDL progress is hard to detect.

2.2.3 Water Clarity

The Chesapeake Bay Program tracks water clarity with an indicator that reflects "achievement or non-achievement of water quality standards for water clarity/underwater grasses within 91 tidal water segments containing the shallow water habitat designated use."[38] Recent attainment has been low, at around 10%, but this indicator has been steadily improving since 1986 (**Figure A-3**).

The indicator that UMCES uses for water clarity measures the proportion of time that water clarity is below literature-based threshold values (not water quality standards) between March and November.[39] According to this indicator, water clarity has been steadily declining to current scores of 10-20% (**Figure A-4**).

2.2.4 Submerged Aquatic Vegetation

The Chesapeake Bay Program also tracks aquatic vegetation with a metric that quantifies vegetation acreage. In **Figure A-5** we plot annual acreage estimates as a fraction of the 185,000-acre goal. Although there is a slight long-term increase, the past 10 years have seen a decline, and the estimated acreage for 2012 was lower than it has been at any time since 1984. For this indicator the UMCES data are almost identical to the Chesapeake Bay Program data.[40]

2.2.5 Bottom Habitat Health

The Chesapeake Bay Program calculates a "Benthic Index of Biological Integrity," using a 1 through 5 scoring system, and using five indicators of biodiversity and ecosystem health.[41] The Bay Program goal is to have 100% of sites score 3 or higher. Unlike other indicators, Benthic Index scores have only been calculated for the 1996-2012 period. **Figure A-6** shows that only 50% of sites currently meet this goal, a percentage that has stayed essentially unchanged since 1996. UMCES calculates a similar (or the same) Index, and shows similar results.[42]

2.2.6 Species abundance

The Bay Program tracks the abundance of several important aquatic species, as shown in **Figure A-7**. Here it is important to note that nutrient and sediment loads are only part of the picture – commercial fishing pressure, for example, also has a direct impact on species abundance. With that in mind, the Bay Program data show that blue crabs, bass and shad are all currently below target levels, and menhaden, for which there is no target, is present at much lower levels than it was in the 1970s and 80s.

2.3. Combined indicators

The Bay Program calculates an overall water quality indicator that synthesizes attainment of dissolved oxygen, chlorophyll a, water clarity, and aquatic vegetation standards. According to this indicator, water quality has been improving slightly over the long term, but has been flat over the past 10 years at 30-40% attainment (see **Figure A-10**). UMCES calculates a "Bay Health Index" that averages seven indicators.[43] According to this indicator, bay health has been declining slightly over the long term, but like the Chesapeake Bay Program indicator, this indicator shows a trend that is essentially flat over the past 10 years (see **Figure A-11**).

2.4 Milestone progress

The practical steps that each state must take to reduce pollution, or in the case of monitored point sources, the specific pollution reductions that states must achieve, are tracked at the state level through two-year "milestones."[44] Within each state, milestones are grouped by pollution source sector. This section summarizes progress across all sectors; agricultural progress is discussed in greater detail in the next section of this report.

The Bay Program reports on how well the states did at meeting milestones for 2009-2011 and for 2012-2013. It is important to note that that "[t]he 2009-2011 milestones were developed prior to the limits set by the Bay TMDL," and are therefore not directly comparable with TMDL progress.[45] That said, the Bay states largely accomplished their 2009-2011 goals. Progress in meeting wastewater goals, for example, ranged from 67% (phosphorus, New York) to over 2,000% (nitrogen, Virginia), and was typically well above 100%. Progress in meeting urban and suburban commitments (for example, the construction of erosion and sediment control) was also typically well over 100%.

The Bay Program reported on 2013 milestone achievement in June 2014, and the results largely mirrored 2009-2011 milestone achievement. 2013 targets for most Urban, Wastewater, and Septic practices were met (see Appendix **Table A-1**). Progress in the agricultural sector was uneven. On one hand, many targets for agricultural practices were achieved or surpassed (see Appendix **Table A-2**). On the other hand, the Bay Program made note of several "shortfalls," including Maryland's failure to promulgate a Phosphorus Management Tool and failure to adequately track and verify BMP implementation,[46] and Pennsylvania's general failure to meet pollution reduction targets for agriculture.[47]

2.5 TMDL progress summary

The indicators discussed above are mixed. The Bay states have made considerable progress in implementing the practices that are expected to reduce pollution loads, and models that take these practices into account estimate that loads should be declining. However, estimates of annual loads that use real monitoring data do not show the same progress: Over the long term, nitrogen loads appear to be declining at a much slower rate than the models predict. Phosphorus and sediment loads appear to be increasing. Meanwhile, indicators of water quality and aquatic life show little evidence that the health of the ecosystem is improving. If ecological integrity is not recovering, and if pollution loads are not declining as fast as they should, then it stands to reason that the policies and practices implemented to date have not been sufficient.

3. Agricultural sources of pollution

Agriculture, as mentioned above, is the largest source of nitrogen, phosphorus, and sediment loads entering the Bay, and the reduction of agricultural loads is therefore central to the success of the TMDL. Unfortunately, agricultural loads are uniquely difficult to measure. The discreet, monitored discharge points from CAFOs are a small fraction of the total load (see "Agriculture-Regulated" in **Table 1** above); the majority of agricultural loads come from the nonpoint sources, including manure and commercial fertilizer applied to agricultural fields ("Agriculture" in **Table 1**). These loads travel over land and through groundwater with variable travel times. By the time pollutants reach a stream, it is very difficult to identify their origins. For this reason, agricultural load estimates rely heavily on simulation models. Since TMDL targets and progress all depend on the output of these models, it is critically important to evaluate the model inputs. If model inputs are uncertain or inaccurate, then modeled loads will be equally uncertain or inaccurate. Before we look at model inputs, however, we briefly review the modeled loads that policymakers are using to evaluate and plan TMDL compliance.

The agricultural loads modeled by the Bay Program using the phase 5.3.2 Watershed Model are shown in **Table 2** below. These estimates correspond to the modeled loads shown in **Figures 1**, **2**, and **3** above (but only represent the agricultural fraction of total loads), and are based on hypothetical average weather conditions. It is clear that modeled agricultural loads, like modeled total loads, are declining.

Table 2. Modeled loads from agriculture to the Chesapeake Bay (millions of pounds).[48]

	1985	2009	2013
Nitrogen	141.8	113.8	107.4
Phosphorus	11.0	10.5	9.9
Sediment	7,190	5,295	4,800

Another large-scale simulation of agricultural loads in the Chesapeake Bay watershed, run by the USDA Conservation Effects Assessment Project, used surveys and hydrologic models to compare a baseline period (2003-2006) to conditions in 2011. This simulation estimated that loads of nitrogen, phosphorus, and sediment delivered to the Bay declined by 6%, 5%, and 8%, respectively.[49]

Modeling is not uniformly positive,[50] but overall it is safe to say that the models show a reduction in agricultural loads. However, these model predictions are at odds with several other pieces of information:

- Total annual loads estimated by the Bay Program show long-term trends that are only slightly decreasing (nitrogen) or are increasing (phosphorus and sediment).[51] Agriculture is the dominant component of these loads, and other major components such as wastewater are known to be decreasing.[52] These trends therefore suggest that agricultural loads are increasing.

- Indicators of water quality are mixed, but the overall trend seems to be in the direction of persistently poor or declining health (see section 2 above). Even if we assume some time lag between pollution discharges and ecological effects, those effects should be evident now: The Bay Program model shows significant reductions in modeled loads between 1985 and 2009; reductions therefore should have been achieved a minimum of three years before the most recent Bay health data (from 2012 and 2013).

- The ultimate sources of most agricultural pollutants – manure and commercial fertilizer – may to be increasing. According to the USDA report cited above, the number of acres fertilized in 2011 was higher than it was in 2003-06, including a 30% increase in the number of acres with manure spreading.[53] These applications are also becoming more intensive: Per acre, the pounds of nitrogen applied in commercial fertilizer increased by 9%, the pounds of nitrogen applied in manure increased by 13%, the pounds of phosphorus applied in commercial fertilizer increased by 6%, and the pounds of phosphorus applied in manure increased by 11%.[54]

In short, the models appear to be overestimating the pollution reductions from agriculture. There are several possible explanations for this. First, the models, and in particular the model used by the USDA, are based on average historical weather patterns (the USDA model uses weather history from 1960-2011). We now know, however, that climate change has already caused a dramatic increase in the amount of precipitation that falls in heavy events.[55] Current and future weather patterns are going to be very different than historical weather, and the average historical weather patterns will not produce realistic simulations. Here it is important to point out that phosphorus and sediment loads were very high in 2011, when the region was hit with heavy storm activity including Hurricane Irene and Tropical Storm Lee. According to the Bay Program's Scientific and Technical Advisory Committee (STAC), "while the 2011 Tropical Storm Lee event produced less than 2% of the total annual stream flow during 2002-2011, it accounted for 22% of the P and 39% of the suspended sediment transported past the Conowingo stream gauge during the same time period."[56] This kind of weather event will affect loads in the future, and must be incorporated into model runs in order to produce realistic simulations.

Second, the information about land use practices may be biased. The USDA modeling effort, in particular, was based on volunteer farmer surveys, and may have overselected for conservation-minded farmers who implement more than the typical number of best management practices.

Third, there is a time lag, not adequately captured by the models, between pollution reductions in the agricultural fields and reductions in pollution loads entering the Bay; this can be attributed to variable groundwater travel times, to phosphorus saturation of soil, and to in-stream cycling of phosphorus and sediment.[57] It is important to note that this time lag applies to some, but not all, pollution pathways, and that some degree of response should occur shortly after land use changes. According to STAC:

> Initial response can be immediate or delayed depending on the relative amount of young groundwater components in discharge. If the groundwater flow system is thin, shallow, and highly transmissive, then the initial response of discharge to a landscape may be immediate (few years or less). Even in the classic "exponential model" for groundwater discharge from thicker unconsolidated aquifers (similar to some coastal plain models), where the mean age of discharge may be decades, young water is a substantial component of the mixture, so a partial initial response may not be delayed, although it may be more difficult to detect.[58]

Others have noted that "[i]n settings where cropland is located directly adjacent to surface waters, reductions in root zone nitrate leaching rates will result in minor reductions in subsurface N discharge rates within 3 to 5 years and major reductions in 5 to 10 years."[59] In addition, the fraction of groundwater considered "young" may depend on location: According to one recent report, half of groundwater discharging to the Potomac and Susquehanna River systems is less than one year old, while this fraction may be closer to 30% for parts of the Delmarva Peninsula.[60] Lag times, then, can help to explain some, but not all, of any discrepancy between models and actual loads.

Finally, the best management practices themselves may not be performing as well as the models predict, either because they are not adequately implemented and maintained or because the estimates of how well they work are overly optimistic. This last possibility is addressed in detail in Section 5. First, however, we turn to an important and under-utilized source of data – water quality monitoring in smaller agricultural sub-watersheds.

4. Monitoring in sub-watersheds

In this section we explore one of the principle data gaps limiting our ability to accurately track agricultural pollution reductions. The Chesapeake Bay Program Partnership maintains or has access to an extensive monitoring network, particularly in tidal areas; we explore these data for Maryland's lower eastern shore in a companion report that will be released soon. However, even with the large amount of available data, there continue to be gaps in upstream subwatersheds where agriculture is the dominant land use. As discussed above, it appears likely that current Bay models are overestimating pollution reductions from agriculture on a Bay-wide scale. In order to better illustrate the problem and offer recommendations, this section will focus on the Choptank River basin on Maryland's eastern shore.

4.1 The Choptank River: Modeled loads and water quality monitoring data

The Choptank River watershed is a largely agricultural area, with 62% agricultural land cover and only 5% urban or developed land.[61] We selected this watershed as an illustration because of its agricultural nature, and because much of the research into the pollution reductions from agricultural land use practices is being conducted here (see next section). As in the Bay as a whole, there is appears to be a discrepancy between modeling and monitoring data in the Choptank River watershed.

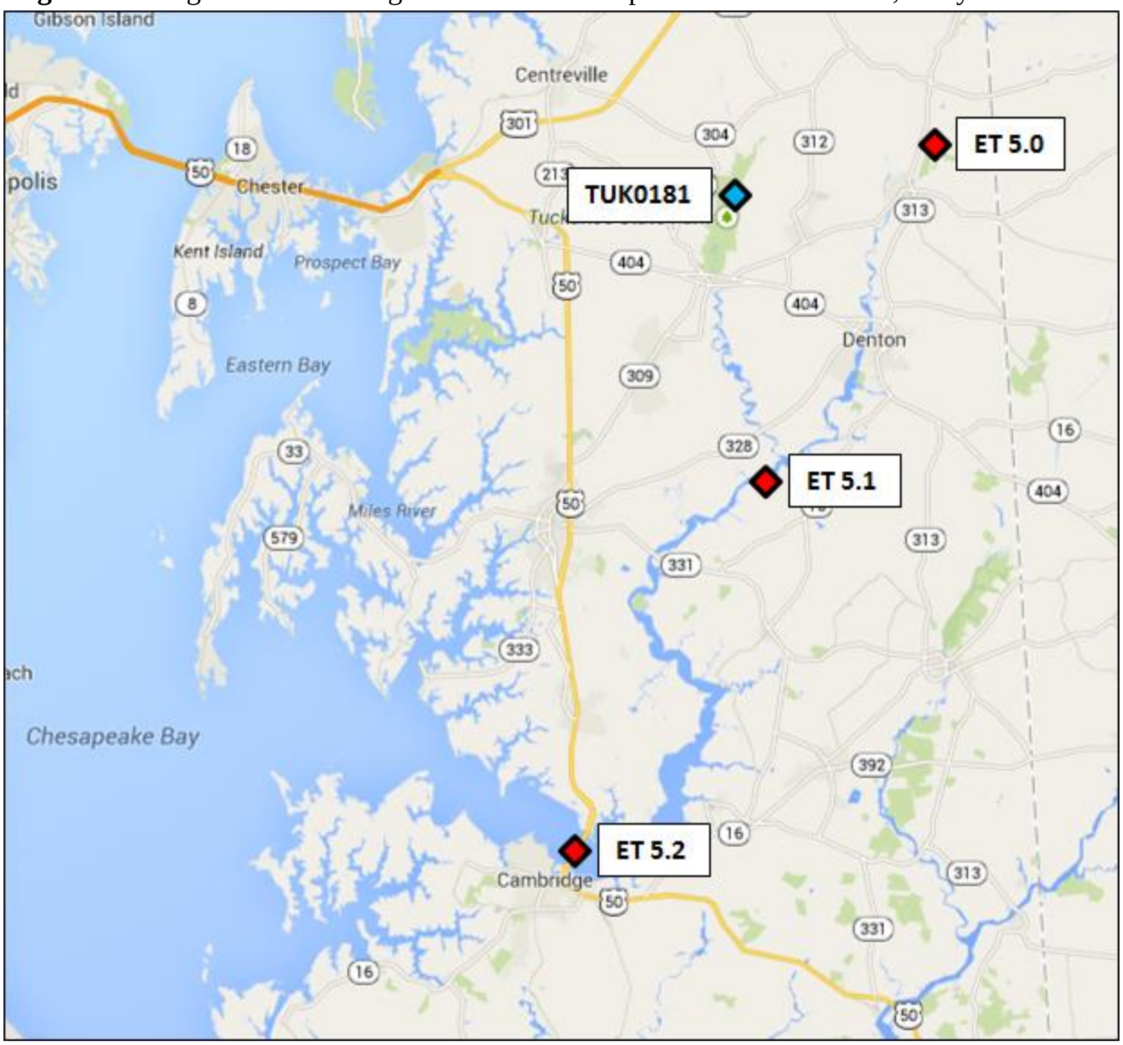
The Choptank River is shown in **Figure 4**. Estimates of nutrient and sediment loads from the Choptank can be obtained in several ways:

- First, there are model estimates. Maryland's Bay Stat website presents total and sector-specific load estimates for the Choptank River that were generated using the Chesapeake Bay Model.[62] That data presentation also includes pollution reduction targets for nitrogen and phosphorus.

- Second, there are load estimates from the United States Geological Survey (USGS) for one upstream sub-watershed of the Choptank watershed.[63] The USGS station is in Greensboro, MD, and is shown at the **Figure 4** location labelled ET5.0.[64] The sub-basin draining through this station includes land in Maryland and Delaware, and is roughly half agricultural.[65]

- Finally, there are water quality monitoring data. Although pollution load estimates and water quality are not directly comparable, as lag times, meteorology, and other factors will affect how and when load estimates translate to water quality improvements, long-term trends in predicted loads can be compared to long-term trends in the concentrations of nutrients and sediment in the Choptank River and its tributaries. If loads are declining, and if flow is relatively stable over the long term, then the concentrations of nutrients and sediments should also be declining. The Bay Program water quality database includes long-term data from three monitoring stations in the Choptank River, shown in **Figure 4**. These stations have been sampled at least monthly since 1984 or earlier. The Maryland Department of Natural Resources has monitored non-tidal station TUK0181, also shown in **Figure 4**, on a monthly basis since July 2005.[66] This station is in Tuckahoe Creek, a tributary to the Choptank River. The database also includes a limited amount of data from other stations in the Choptank River or Tuckahoe Creek that were monitored between April and October, 2006-2008. Data from those stations closely track data from nearby long-term monitoring stations for the April-October period (data not shown here).

Figure 4: Long-term monitoring stations in the Choptank River watershed, Maryland.



4.1.1 Choptank load models

Model simulations, as shown in **Figures 5 through 7**, show declining loads of nitrogen, phosphorus, and sediment over the past 30 years. According to these models, total pollution loads and loads from agriculture have been declining more or less in parallel and are on track to meet 2017 targets.

Figure 5: Simulated nitrogen loads from the Choptank River.[67]

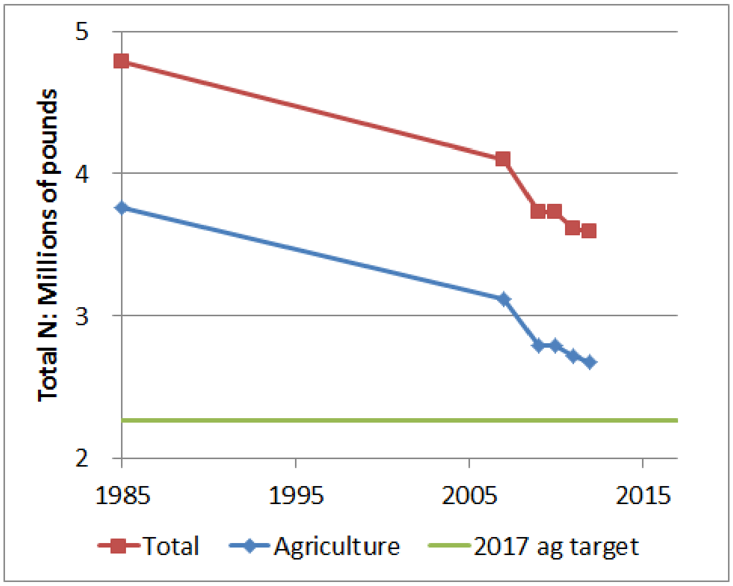


Figure 6: Simulated phosphorus loads from the Choptank River.[68]

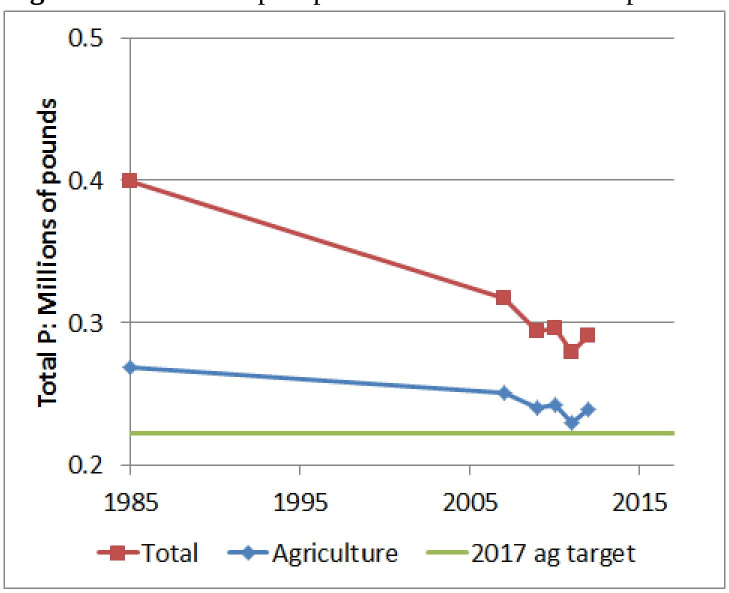
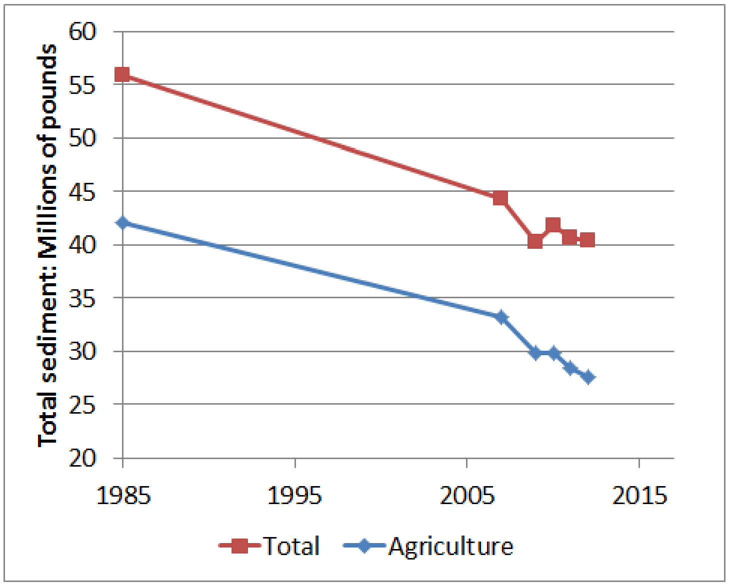


Figure 7: Simulated sediment loads from the Choptank River.[69]



4.2.2 Pollution load measurements in Greensboro, MD

The USGS station in Greensboro, which reflects one sub-basin of the Choptank watershed, shows trends that are the opposite of model estimates for the watershed as a whole. **Figures 8 through 10** show loads of all three pollutants increasing by at least a factor of two over the same time period covered by model estimates.[70]

Figure 8: Total nitrogen loads at the USGS station in Greensboro, MD (millions of pounds per year).[71]

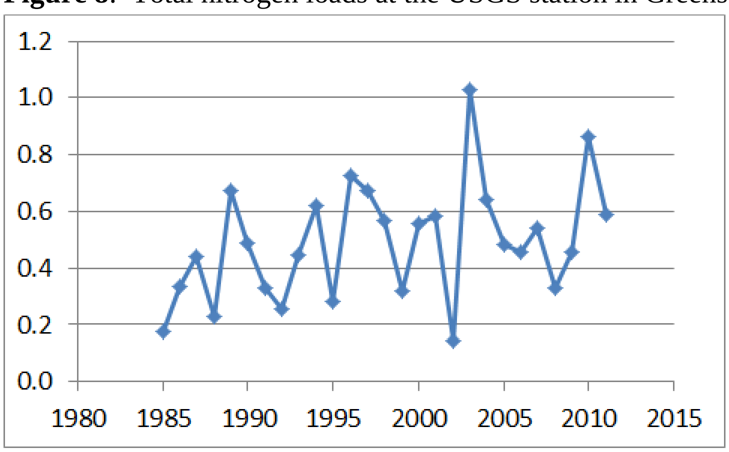


Figure 9: Total phosphorus loads at the USGS station in Greensboro, MD (millions of pounds per year).[72]

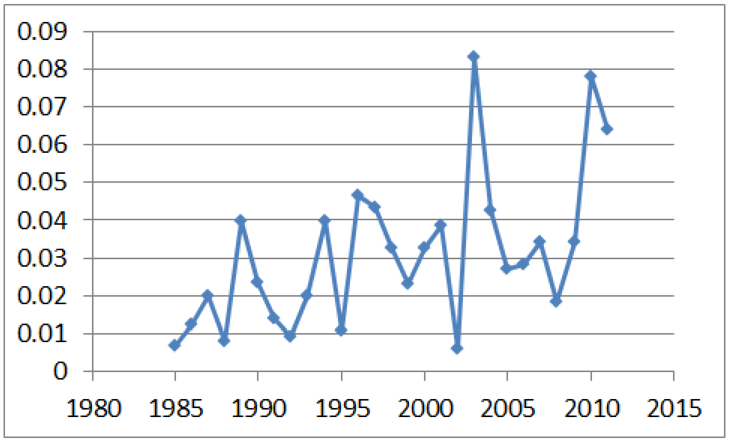
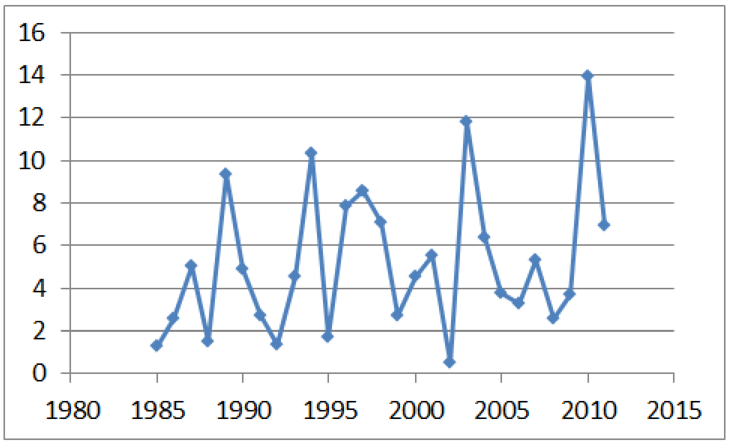


Figure 10: Total sediment loads at the USGS station in Greensboro, MD (millions of pounds per year).[73]



4.2.3. Water quality monitoring data in the Choptank watershed

Finally, with the caveat that water quality and loads are not directly comparable due to the effects of lag times and changes in flow volume over time, general trends in water quality monitoring data from the four stations shown in **Figure 4** can be compared to trends in simulated loads to look at overall consistency between the trends. EIP averaged the concentrations of each pollutant for each complete year (years having 12 months of data), then calculated 3-year moving averages of these annual estimates to assess temporal trends. For purposes of this discussion we focused on shallow water samples.[74]

Nitrogen trends in the Choptank diverge dramatically from trends in modeled loads. **Figure 11** shows annual average concentrations of total nitrogen from the four stations. Although models predict a 25% decline in nitrogen loads over this period, monitoring data show an increase in surface water concentrations ranging from 11% (ET5.2) to 59% (ET5.1).

Figure 11: Measured concentrations of total nitrogen in the Choptank River and Tuckahoe Creek.[75]

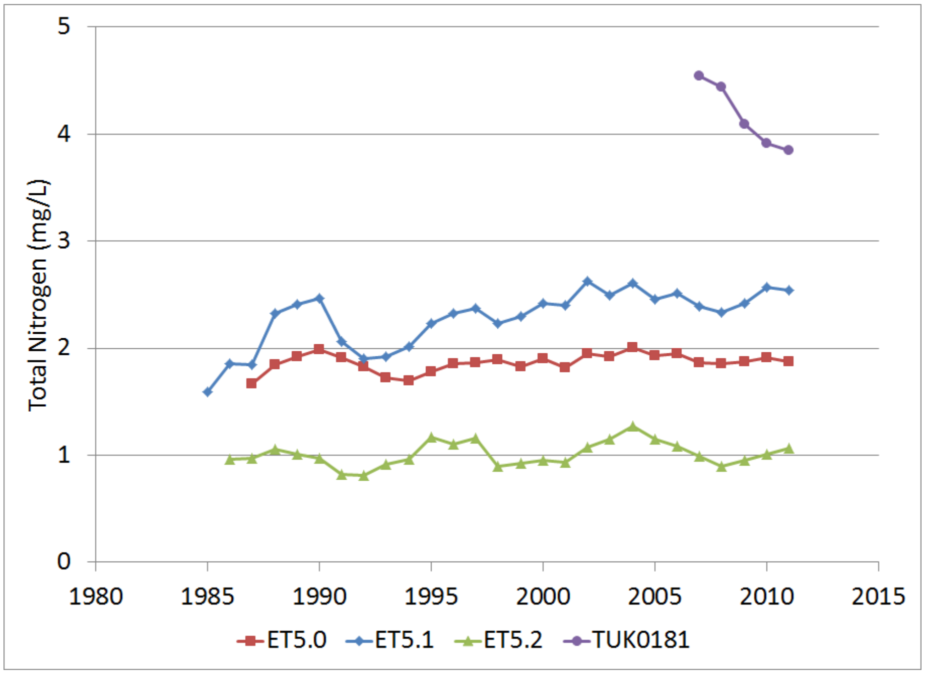
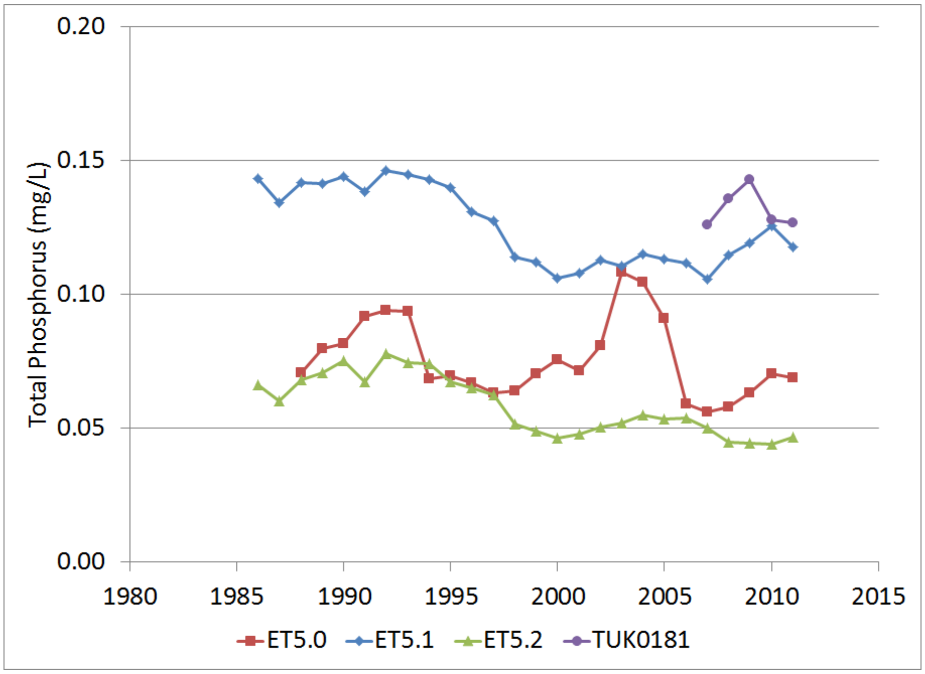


Figure 11 also shows clear differences between monitoring stations. In general, concentrations appear to increase from ET5.0 (farthest upstream on the Choptank River) to ET5.1, then decrease by the time the river reaches ET5.2. Data from station TUK0181, upstream on Tuckahoe Creek, stand out as distinctly higher than the other stations. The difference between the two upstream stations, ET5.0 and TUK0181, is likely attributable to the influence of agriculture. Land cover in the drainage feeding the Choptank at ET5.0 is less agricultural (49%) than the watershed as a whole (62%).[76] The upstream sub-basins surrounding Tuckahoe Creek, on the other hand, have more agricultural land cover, averaging 67% in a group of sub-basins monitored by University of Maryland researchers.[77] Like TUK0181, these more agricultural sub-basins show relatively nitrogen concentrations in surface water, averaging 5.5 mg/L in 2003-2006.[78] Furthermore, among these Choptank sub-basins the researchers observed a significant positive correlation between agricultural land cover and nitrogen concentrations.[79] There is therefore a clear connection between extensive agricultural land use in this watershed and relatively high nitrogen concentrations in local waterways.

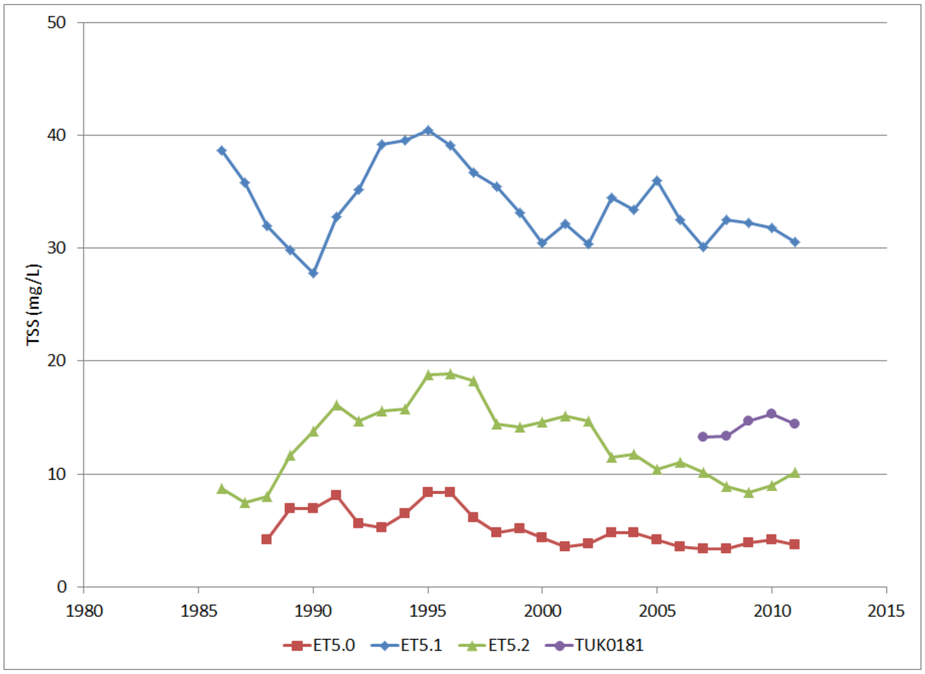
Phosphorus trends have been roughly consistent with model predictions. Concentrations at ET5.1 and ET5.2 declined by 18% and 30%, respectively, between 1985 and 2012, although concentrations at Station ET5.1 appear to be increasing in recent years (**Figure 12**). Modeling for the Choptank, as discussed above, estimates a 27% reduction in phosphorus loads over the same period. Phosphorus concentrations in the headwaters, at stations ET5.0 and TUK0181, show no discernible trend. We reiterate here that phosphorus *loads* at the USGS Greensboro station, co-located with station ET5.0,[80] have been increasing (see **Figure 9** above).[81]

Figure 12: Measured concentrations of total phosphorus in the Choptank River and Tuckahoe Creek.[82]



Sediment trends are more complicated. As discussed above, models predict a 28% decline in sediment loads since 1985. Data from Station ET5.1 are consistent with this prediction: **Figure 13** shows that shallow surface water samples at station ET5.1 have declined by 21% over this period. Concentrations in bottom-layer water are generally twice as high, but show the same trend, with a decline of 32% (data not shown). Data from the other monitoring stations have varied over time, but the change between the mid-1980s and today is very small. Although shallow water at Station ET5.2 shows an overall increase of roughly 17%, this is an unusual instance of a station where trends in the different water layers diverge: sediment concentrations in the bottom layer at this station, which are generally twice as high as shallow water concentrations, have declined by roughly 12% over the same period (data not shown). Taken together, trends in sediment concentrations at station ET5.2 appear to be roughly flat.

Figure 13: Measured concentrations of Total Suspended Solids in the Choptank River and Tuckahoe Creek.[83]



4.2.4 Choptank river watershed data summary

To summarize, nitrogen concentrations in the Choptank watershed surface water have been increasing over the past 30 years, calling into question model estimates of a substantial nitrogen load decline over the same period. University of Maryland research in small tributaries and upstream sub-basins within the Choptank basin shows that sub-basins with more agriculture have higher nitrogen concentrations, and that agriculture may therefore be driving the discrepancy between models and monitoring data. Models also suggest that phosphorus and sediment loads should have declined over the past 30 years; although some water quality monitoring data are consistent with this trend, other data show long-term trends that are essentially flat. Pollution load estimates for the sub-basin upstream of the USGS Greensboro station, in contrast to trends in simulated loads for the watershed as a whole, show significant increases for nitrogen, phosphorus, and sediment. In short, there are troubling discrepancies between simulated loads for this watershed and actual monitoring data, and agriculture is a likely cause.

4.2 Recommendations for sub-watershed monitoring

In the Choptank River watershed, the state monitoring database is focused on the main stem of the Choptank River, with very little monitoring in the smaller, upstream tributaries. If Maryland officials hope to understand the inaccuracies in nitrogen load models in the Choptank, they should focus monitoring on the upstream, agricultural areas.

This recommendation can also be generalized – if state agencies hope to understand the discrepancies between Bay-wide model predictions and actual pollution loads, they should start by collecting monitoring data from small watersheds where agricultural loads are likely to dominate, and where the effects of changes in agricultural land use practices can be verified.

The Lycoming County (Pennsylvania) Farm Project is a good example of the kind of exercise that could be reproduced elsewhere: This project was carried out collaboratively between the Lycoming County Conservation District, the Lycoming County Planning Commission, Land Studies, Inc., and the Lycoming College Clean Water Institute, with funding from the Pennsylvania DEP and other sources.[84] The group identified a small stream that ran through four contiguous farms and set up monitoring sites upstream, downstream, and in the middle of that area. After collecting several months of background data, the group worked with the four farmers to introduce new Best Management Practices (BMPs), mainly grass buffers and livestock exclusion fencing. Since then, the group has been monitoring water quality and flow, and is able to estimate pollution loads over time. Although it is too soon to interpret the results, the project illustrates an ideal geographic scale and study design.

The Bay states should implement the kinds of monitoring projects that have been carried out in the Choptank River and in Lycoming County in order to accomplish two goals: To better quantify pollution loads from agricultural sub-watersheds, and to evaluate the effectiveness of the agricultural Best Management Practices put into place to reduce loads. The next section explores the latter goal in more detail.

5. Agricultural BMPs

Agricultural Best Management Practices (BMPs) are farming and land-use practices that can help reduce pollution loads. Common BMPs include forest buffers to trap sediment runoff and absorb nutrients in groundwater, winter cover crops to stabilize the soil and keep nutrients cycling in and above the root zone, and stream fencing to keep pastured animals out of waterways. All of these BMPS produce some reduction in pollution loads, and some of them, like stream fencing, produce an immediate and visible change. The question that we address below is not whether the BMPs work, but rather how well they work. The Bay Model assumes that each BMP will reduce pollution loads by a certain amount, in some cases depending on farm-specific factors like crop, geographic location, or planting dates. Forest buffers in the Inner Coastal Plain, for example, are expected to reduce nitrogen, phosphorus, and sediment loads by 65%, 42%, and 56%, respectively, in addition to any reductions that would be attributed to the land use change in the buffer itself.[85] Drilled rye planted as an early cover crop in the "coastal plain/piedmont/crystalline/karst settings" is expected to reduce nitrogen, phosphorus and sediment loads by 45%, 15%, and 20%.[86] A full inventory of BMP effectiveness estimates can be found in the documentation for the Bay Model;[87] that document builds on and frequently cross-references a comprehensive report on the expert-led development of the effectiveness estimates.[88] BMP effectiveness values are continuously reviewed and updated by the Bay Program,[89] but there is still significant uncertainty around their performance. A number of important state-level policies depend on these BMPs to ensure TMDL progress. As we describe below, the uncertainties around BMP effectiveness may be a fatal flaw in these policies unless they incorporate a meaningful margin of safety.

5.1 BMP uncertainty

BMP effectiveness estimates, also known as "efficiencies," are inherently uncertain.[90] There are several important sources of uncertainty: First, there is considerable variability and heterogeneity in weather conditions, in topography, in soil type, and in the ways in which BMPs are operated and maintained. This variability means that a BMP in one place and time will work differently than a BMP in another place and time. Second, there is often a time lag between when a BMP is implemented and when the maximum pollution reductions are achieved. Third, some BMPs are planned and/or implemented, but not adequately followed through, leading to failed credit generation.[91]

Another, substantial source of uncertainty has to do with the BMP effectiveness estimates themselves. These effectiveness estimates are generally based on carefully controlled, small-scale research studies. According to Bay Model documentation:

> On a research site, the BMP is designed, operated, and maintained in a very controlled manner. That ensures that the BMP is achieving its full potential or is near its highest efficiency. On a watershed scale, the same level of control and oversight is impossible.[92]

In other words, the BMP effectiveness estimates are typically best-case, overly optimistic estimates. This source of uncertainty is therefore better characterized as a bias.

The presence of a bias is borne out in the limited amount of research into BMP effectiveness in the real world. We explore some specific research projects in the Chesapeake Bay watershed in the next section, but in general, BMP effectiveness values overestimate real-world performance.[93] According to the EPA, "few, if any, data suggest actual watershed-wide implementation efficiencies as high as those in the research literature."[94]

In some cases, the Bay Model BMP effectiveness estimates reflect adjustments that were made to account for this bias. Research estimates for cover crop effectiveness, for example, were reduced by 25% in an attempt to approximate realistic estimates for average conditions.[95] It is important to note that these adjustments, when they were made, only accounted for a perceived bias, and did not eliminate other sources of uncertainty. Furthermore, although the adjustments may have reduced the bias, there is no guarantee that the bias was eliminated (see the discussion of real-world effectiveness in the following section). Is also important to emphasize that the BMP effectiveness estimates were not designed to be "conservative." Instead, "[t]he objective was to develop BMP definitions and effectiveness estimates that represent the average operational condition of the entire watershed."[96]

To summarize, the final BMP effectiveness estimates were intended to be realistic, but are associated with considerable uncertainty, including uncertainty around how well BMPs are implemented and maintained and uncertainty related to meteorological variability.[97] In addition, the bias that results from assuming that BMPs in the real world, at the watershed scale, will perform as well as they do at the research scale has been reduced in some cases, but may still be inherent in many of the BMP effectiveness estimates. The next section will review research into BMP effectiveness in the Chesapeake Bay watershed.

5.2 Research into BMP effectiveness in the real world

> *"Several studies have shown that when BMPs are applied across even a small watershed, the resulting improvement in water quality is far less than would have been projected on the basis of research-scale data." (U.S. EPA, 2010)*[98]

As the previous section explained, BMPs on research plots perform much better than they do in the real world. Unfortunately, field-testing BMPs after they are implemented is very difficult. As the National Research Council noted, "[f]ield monitoring of BMPs on a comprehensive basis is neither practical nor affordable."[99] This means that attempts to verify BMP effectiveness in the real world are rare. They do exist, however. Some of the most comprehensive research into real-world BMP effectiveness has come from the University of Maryland Center for Environmental Science (UMCES), where researchers have been studying multiple sub-watersheds on Maryland's Eastern Shore.

This section will describe the UMCES research in some detail, but first it is important to understand some of the factors influencing the migration of nutrient pollution from fields to surface water. First, nitrogen and phosphorus behave differently: Nitrate, the dominant source of nitrogen in agricultural discharges, is soluble and readily leaches out of fields.[100] The solubility of phosphorus depends on the degree of phosphorus saturation in the soil; below a certain level of saturation phosphorus readily binds to soil particles, but as saturation increases, solubility also rapidly increases.[101] Second, nutrients can travel in surface runoff, especially during heavy rain events ("stormflow"), or they can travel through shallow groundwater, entering streams as "baseflow." Both can be important pathways for phosphorus, but in general the baseflow pathway is more significant for nitrogen.[102] Third, soil can be well-drained or poorly-drained. Anoxic groundwater in poorly-drained areas supports nitrogen loss through denitrification, while groundwater in well-drained areas is more likely to be enriched in nitrogen.[103] Finally, land use is often a much stronger determinant of nutrient loading than anything else; a predominantly agricultural watershed is likely to have much higher loadings than a predominantly forested watershed. The UMCES research described below has had to evaluate BMP effectiveness while controlling for these and other factors.

5.2.1 Riparian buffers

The most intensively studied BMP in the UMCES research program has been riparian buffers. Research has looked closely at how riparian buffers work, how well they work in specific locations, and how well they work on a watershed scale. Riparian buffers can reduce nitrogen and phosphorus discharges in four ways: by trapping eroded soil, by creating anoxic groundwater that facilitates the conversion of nitrate to N_2 gas (denitrification), by taking up nutrients and storing them in plant material, and by allowing low-nutrient precipitation to dilute high-nutrient groundwater.[104] The degree to which underlying soil naturally drains can affect the efficiency of the denitrification process, as groundwater in well-drained areas may flow beneath and bypass the anoxic, denitrifying root zone.[105]

The Chesapeake Bay model assumes that forest buffers at least 35 feet wide will reduce nitrogen by 19-65%, depending on local geography and hydrology, and reduce phosphorus by 30-45%, in addition to any reductions attributable to the land use change in the buffer itself.[106] The Bay model assumes that grass buffers, again at least 35 feet wide, will reduce nitrogen by 13-46% and phosphorus by 30-45%.[107] Most of the research supporting these estimates comes from plot-scale studies of established buffers.[108]

Watershed-scale studies, unlike plot-scale studies, have not been able to detect any impact of buffers on nitrogen and phosphorus in baseflow. University of Maryland researchers studied 15 subwatersheds within the Choptank River basin on Maryland's Eastern shore. The subwatersheds had a wide range of old and new buffers.[109] The percentage of streamsides with "established" buffers (in place in 1998) ranged from 10-62%.[110] The percentage of streamsides planted with buffers between 1998 and 2005, as part of the Conservation Reserve Enhancement Program (CREP), ranged from 1-30%.[111]

Sutton et al. looked at the nutrient concentrations in surface water leaving each subwatershed in 1986 (pre-CREP implementation) and in monthly sampling during 2003-2006. In the raw data, there was no relationship between the amount of riparian buffers – old, new, or total – and nitrogen or phosphorus concentrations.[112] The authors did detect a significant relationship between nutrient concentrations and the percentage of each subwatershed in agricultural land use, however.[113] In order to correct for the effect of agricultural land use, the authors examined the residuals from regressions of nutrient concentrations against % agriculture.[114] The authors reported that the residuals were not related to CREP buffers.[115] In other words, nutrient concentrations, after adjusting for % agriculture, were not affected by CREP buffers.

Since CREP buffers are relatively new, and represent a fraction of total buffers, we also plotted the residuals from the models of Sutton et al. against established buffer percentages and total buffer percentages. **Figures 11** and **12** show that nitrogen and phosphorus residuals were not related to either variable. Sutton et al. concluded that "8 years after the beginning of restoration under the [CREP] program, an average increase of 11% in riparian buffers restored under CREP has not yielded significant, detectable effect[s] on stream nutrient concentrations."[116] Perhaps more importantly, their research also shows that older, established buffers did not have a detectable effect on nutrient concentrations.

More intensive research into one of the 15 subwatersheds, the German Branch, including a nutrient budget from the early 1990s, allowed the authors to predict the effect that increasing buffers from 62% to 72% of streams would have on nitrogen concentrations. Using low and high literature values, they predicted that baseflow nitrogen should have declined by 0.8 to 3.7 mg/L. In fact, nitrogen concentrations increased slightly. In light of other factors, including the possibility of increased fertilizer applications, the authors concluded that observations could be consistent with the low nitrogen removal estimate, but that "it is not likely that restored buffers in German Branch have a high removal rate."[117]

Figure 11: Nitrogen model residuals as a function of established or total buffer percentage for each subwatershed in the Choptank River study of Sutton et al. 2010.[118]

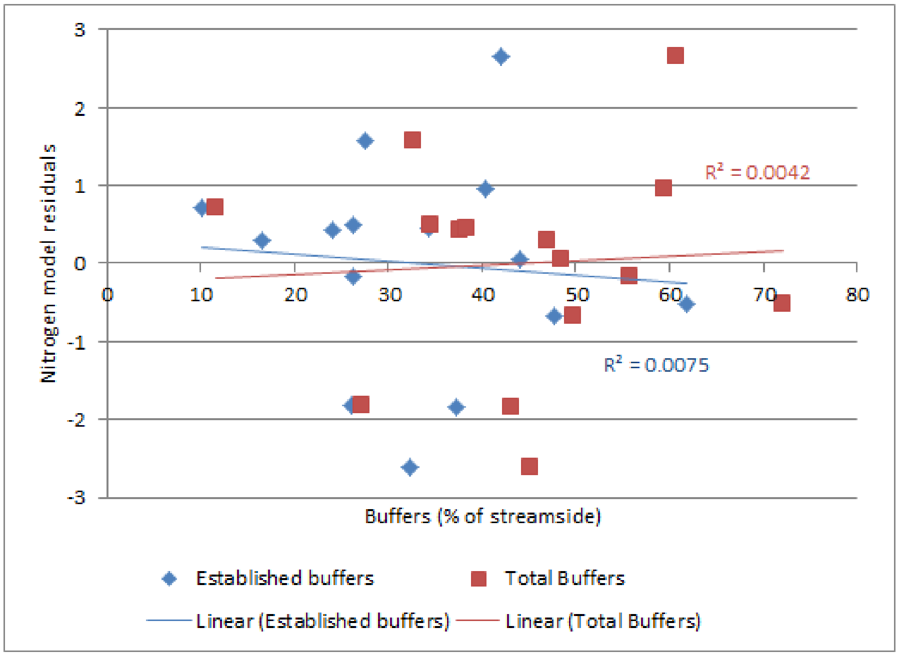
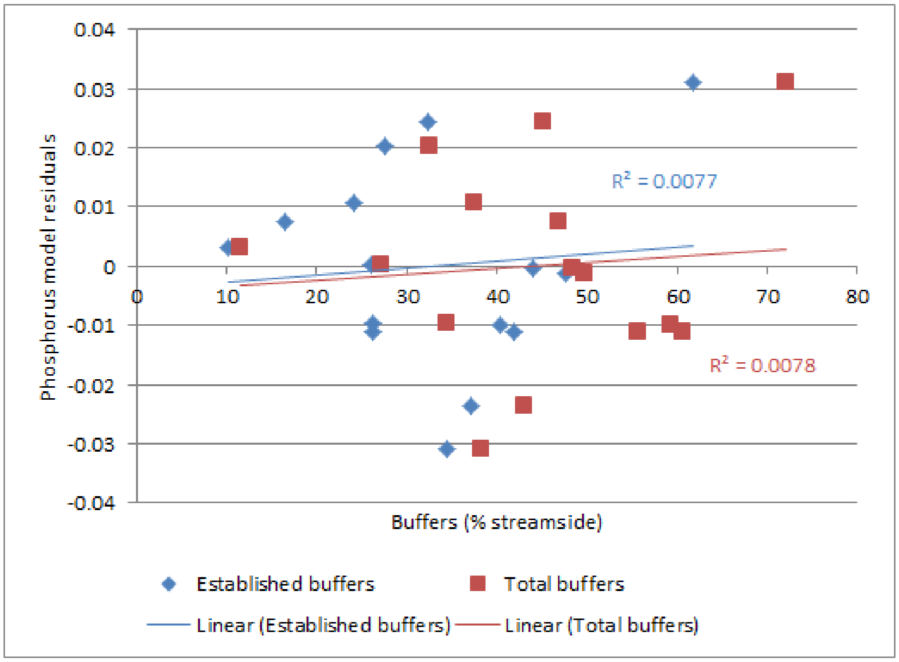


Figure 12: Phosphorus model residuals as a function of established or total buffer percentage for each subwatershed in the Choptank River study of Sutton et al. 2010.[119]



It is important to note that the research described above only looked at baseflow, and not surface runoff during storm events. The authors state that "large amounts of particulate-bound phosphorus also move[] to streams during short-term runoff events; therefore, the data reported here [are] not a complete representation of phosphorus export."[120] Sutton did measure stormflow in two subwatersheds with 45% and 61% of streamsides buffered, and found the 45% buffered subwatershed lost significantly more phosphorus than the 61% buffered subwatershed during storm events.[121] Interestingly, dissolved nitrogen concentrations during storm events were significantly higher in the subwatershed with more buffers.[122]

5.2.2 Cover Crops

As a BMP, cover crops are typically planted at the end of the growing season to stabilize soil and trap nutrients in the root zone or in the cover crops themselves.[123] The extent to which cover crops reduce nutrient and sediment loads depends on several factors, including the species of cover crop, soil type, and the time of planting.[124] Bay Model estimates of nitrogen reductions, for example, range from 9% ("other wheat" planted late in Mesozoic Lowlands/Valley and Ridge Siliciclastic settings) to 45% (drilled rye planted early in Coastal Plain/Piedmont/Crystalline/Karst settings).[125] Phosphorus reductions are estimated to be 15% (early-planted cover crops), 7% (cover crops planted at a standard time), or 0% (late-planted cover crops). Sediment reductions are estimated to be 20% (early planting) 10% (standard planting), or 0% (late planting).[126] These estimates are all based on carefully controlled experimental data, for example from a research plot in Maryland's Wye River basin.[127] The experts reviewing the cover crop literature determined that "the research estimates represent a best-case scenario," and reduced nitrogen reduction estimates by 25% to approximate performance under average conditions.[128] Even with this correction, there is considerable uncertainty around how well cover crops work in the field, and "the aggregate effects of winter cover crops has not been adequately tested at the watershed scale."[129]

5.2.3 Conservation Tillage

Conservation tillage is defined as "planting, growing, and harvesting crops with minimal disturbance to the soil surface."[130] Although the Bay Model accounts for this practice as a land use change, and not a BMP with a specific nutrient reduction efficiency, experts assume that conservation tillage will reduce nitrogen loads by 8%, phosphorus loads by 22%, and sediment loads by 30%.[131] However, watershed-scale research suggests that while conservation tillage can reduce soil erosion and sediment loss, it may increase phosphorus loads by concentrating phosphorus-rich crop litter at the soil surface where it is susceptible to leaching and overland transport.[132]

5.2.4 Nutrient Management Plans

Nutrient Management Plans are defined by the Bay Program as "comprehensive plan[s] that describe[] the optimum use of nutrients to minimize nutrient loss while maintaining yield."[133] Like conservation tillage, NMP implementation is modeled as a land use change rather than a load reduction. The degree to which NMPs reduce nutrient inputs and resulting loads in the model varies by original land use. According to Fisher et al., "the effectiveness of these plans has never been demonstrated on any scale."[134]

5.2.5 Off-stream watering

The Bay Model includes BMPs that reduce or eliminate the amount of time that livestock spend in streams, either with fencing ("Stream Access Control with Fencing) or without fencing ("Alternative Watering Facilities.")[135] Researchers examined the effect of cattle exclusion fencing in the Mill Creek Watershed in Lancaster County, Pennsylvania between 1993 and 2001.[136] Water quality was measured for 3-4 years before, and 3-4 years after, two miles of stream were fenced. Researchers measured both base flow and storm flow.[137] Overall, the treatment basin during the post-treatment period showed nitrogen, phosphorus, and sediment yields that were 19%, 14%, and 37% lower than in the control basin.[138] These reductions are lower than those predicted by the Bay Model (13-46%, 30-45%, and 40-60%, for nitrogen, phosphorus, and sediment, respectively, for "stream access control with fencing.")[139]

5.2.6 The effect of multiple BMPs on water quality

One study in the Upper Pocomoke River watershed measured water quality changes after a nutrient management program that included cover crops and the removal of all poultry litter from the watershed. Five years after the program was implemented, researchers found a 30% reduction in nitrogen concentrations, but no change in phosphorus concentrations.[140]

Other research has focused on a sub-watershed within Maryland's Choptank River basin where multiple BMPs were implemented. The German Branch is a largely agricultural drainage basin with an area of roughly 20 square miles.[141] As part of a Targeted Watershed Project in 1991-95, soil conservation, water quality, and nutrient management plans were implemented on 99% of the watershed.[142] These plans included various BMPs, largely focused on soil erosion control, but also including an increase in conservation tillage and, to a lesser degree, cover crops. At the time, resource managers predicted a 30-40% reduction in nitrogen and phosphorus concentrations.[143] 10 years later, baseflow phosphorus concentrations had declined by 28%, but nitrogen concentrations, contrary to expectations, had increased.[144] This was not due to a time lag – median groundwater residence time in the area is 8 years,[145] and many of the BMPs were intended to control overland discharges, so the effects of the BMPS should have been evident. Cover crops were infrequently used in this watershed, on roughly 2-4% of fields; this may help explain the lack of a nitrogen reduction.[146] It is also important to note that this study did not examine storm flow, which may be responsible for the majority of phosphorus discharges.[147]

A third case study involves both agricultural and non-agricultural BMPs in the Corsica River watershed. Following a 2003 Watershed Restoration Action Strategy, a broad suite of practices was implemented beginning in 2005.[148] Agricultural BMPs included cover crops, small grain enhancements, horse pasture management, and forest buffers; non-agricultural practices included sewage treatment plant upgrades, urban stormwater management, septic upgrades, non-agricultural forest buffers, restored wetlands, restored stream channels, and restored submerged aquatic vegetation and oyster beds. As of 2011, water quality in the watershed had improved, with a decline in nitrogen and phosphorus concentrations in two of three Corsica River tributaries between 2007 and 2011.[149] Since agriculture represented the majority of land use and nitrogen and phosphorus loads in the watershed, it seems logical to conclude that the agricultural BMPs have had some positive effect. On the other hand, the widespread implementation of non-agricultural BMPs makes isolating and quantifying the effect of the agricultural practices in this watershed much more difficult.

5.3 The role of agricultural BMPs in pollution reduction policies

Agricultural BMPs are the central mechanism for reducing pollution loads from the agricultural sector. In most states, the majority of these BMPs are not required, but are instead encouraged through a suite of incentives that varies by state. Some states offer grant funding to help defray the costs of implementation, for example. Other policies offer immunity from new nutrient management regulations for a period of years in exchange for implementation of BMPs. Finally, the Bay states are in various stages of implementing nutrient trading programs where farmers who implement BMPs and reduce loads are able to sell pollution reduction credits. These last two policies are described in more detail below. It should be clear that if the BMPs don't work as well as they are expected to, these policies will not succeed.

5.3.1 Agricultural Certainty

"Agricultural certainty" is a concept that has been implemented in Virginia and is in the process of being implemented in Maryland.[150] The two state programs differ in several ways, but the basic concept is the same: In exchange for implementing an array of BMPs today, a farmer is given legal immunity from new nutrient management regulations for a period of years (9 in Virginia, 10 in Maryland). The BMPs that a farmer must implement are intended to achieve the pollution reductions that the Bay TMDL and any local TMDL require.[151]

Neither program includes a margin of safety. In Maryland, this is a departure from the original terms of the U.S. Department of Agriculture grant that funded the development of the program, which called for a 10-20% margin of safety.[152] If the BMPs that participating farmers implement fail to perform as well as planned, then the participating farmers will not be meeting the TMDL baseline. If the state as a whole fails to meet its TMDL targets, and new regulations are promulgated to cover the shortfall, participating farmers will be immune, and the burden will fall on other farmers or other sectors.

This inequitable result can be avoided with a margin of safety, as the original grant contemplated. According to the Maryland Department of Legislative Services:

> The effectiveness of an agricultural certainty program hinges on the accuracy of initial farm-specific baseline assessments that ensure an agricultural operation is achieving its share of applicable water quality requirements through appropriate BMPs. It may be prudent to establish a cautious baseline assessment for agricultural operations that reflects at least a 10 to 20% margin of safety to offset the possibility of BMPs not achieving necessary pollution reductions.[153]

As we have seen, it is very likely that BMP effectiveness estimates are unrealistically high, and that the presence or absence of a margin of safety will make the difference between an agricultural certainty program that reduces loads and one that allows loads to increase.

5.3.2 Nutrient Trading

Some of the Bay states have chosen to implement nutrient trading policies as a way of reaching TMDL goals more efficiently.[154] Nutrient trading, like pollution trading generally, involves a regulated market in which nutrient credits, representing pounds of nitrogen or phosphorus, are bought and sold. Ideally a nutrient credit market will incentivize nutrient load reductions by allowing sources for whom reductions are relatively easy to sell credits to sources for whom reductions are more difficult. Some trading programs function in part or in whole as offset programs, where new sources are required to offset their load by purchasing credits, thereby retiring credits elsewhere in the system. Note that in both cases the transactions seek reallocate responsibilities for maintaining a targeted load, but do not reduce pollution.

Agricultural BMPs are central to nutrient trading programs because they are the mechanism used by the agricultural sector to generate credits. To take a simplified hypothetical example, a farmer may choose to plant a forest buffer along the boundary between a field and a stream, calculate the reduction in nitrogen and phosphorus loads attributable to the buffer, and sell those credits to a developer that is generating a new load. If the farmer generated 10 pounds of nitrogen credits and sold them to the developer, the developer would be entitled to generate a new load of 10 pounds of nitrogen. Here the potential problem is clear – if the BMP fails to reduce nitrogen loads by 10 pounds, then the overall result is a net increase in loads.

In order to avoid this possibility, and in light of the many uncertainties associated with agricultural BMPs, the EPA expects the Bay states to incorporate an uncertainty ratio of 2:1

when trades involve credits generated and sold by nonpoint sources such as farms.[155] This means that a nutrient credit purchaser would have to buy 2 pounds of nitrogen credits for every pound to be offset. This uncertainty ratio is, in effect, a margin of safety to prevent net increases in nutrient loads.

To date, only Virginia's trading program is consistent with EPA's expectation. Although Maryland and Pennsylvania have retirement and reserve ratios, respectively, of 5-10%, these ratios are intended to achieve other goals (water quality improvements in Maryland, a credit reserve pool in Pennsylvania), and do not provide any margin of safety.[156] Maryland, which does not yet have a formal trading program, has been engaged in a stakeholder process for developing an "Accounting for Growth" (offset) policy. The stakeholder group, which last met before EPA finalized its Technical Memorandum on uncertainty ratios, did not recommend a margin of safety. Maryland's Department of Legislative Services noted the inconsistency and said:

> Because load reductions from nonpoint sources are generally more uncertain than those from point source control technologies, trading programs often impose a "trading ratio" for credit exchanges between point and nonpoint sources. The EPA expects a 2:1 trading ratio for nonpoint source credits purchased by new or expanding point sources to ensure pollution load reductions. In this instance, for every credit needed, the point source must purchase two credits from the nonpoint seller. However, the Accounting for Growth Workgroup recommended a 1:1 trading ratio, with a 10% retirement ratio. Therefore, Maryland will need to discuss further what trading ratio is necessary to meet federal guidelines.[157]

In short, a nutrient trading or offset system without a meaningful margin of safety is likely to lead to a net increase in nutrient loads. Virginia has established a trading program with a 2:1 uncertainty ratio for trades involving nonpoint credit sellers. In order to be consistent with EPA expectations, and in order to prevent load increases, the other Bay states must follow Virginia's lead.

5.4 Agricultural BMPs: Summary

Agricultural BMPs are central to the Bay states' strategies for meeting TMDL goals. BMPs represent the principal mechanism for pollution reductions from the agricultural sector, they are used to estimate load reductions in watershed models, they support state agricultural certainty programs, and they are a central source of nonpoint nutrient credits in state nutrient trading and offset programs. Unfortunately, the ability of these BMPs to reduce nutrient and sediment loads is very uncertain. Although the BMPs have been studied under carefully controlled conditions, there has been little research in the field, at the watershed scale. The research that has been done suggests that the BMPs are not working as well as they were expected to.

If, as it appears, BMPs are not living up to expectations, and absent meaningful margins of safety in state policies, then modeling efforts are overestimating pollution reductions from the agricultural sector, and agricultural certainty and nutrient trading programs are at risk of leading to net increases in pollution loads.

6. Recommendations

Sections 1-4 of this report show that the health of the Chesapeake Bay is not improving, and that loads from agriculture, the largest source of nitrogen, phosphorus, and sediment, are not declining as fast as watershed models predict, if at all. Part of the problem is likely to be agricultural BMPs: If they are not working as well as policymakers hoped that they would, then the model is guaranteed to overestimate pollution reductions. The effectiveness of the BMPs remains a critical area of uncertainty in Bay restoration efforts.

In light of the information discussed above, we have three recommendations for addressing agricultural pollution loads:

1. Reduce nutrient inputs. In the face of stagnant or declining Bay health, an increase in the intensity of nitrogen and phosphorus applications to farm fields (as seen in the USDA report discussed above) is reckless and counterproductive. In the future, fertilizer applications should be planned with more than maximum yields in mind, and should give equal weight to environmental impacts.
2. Collect better monitoring data. In general, the Bay states need better monitoring to track agricultural progress and to show how well BMPs are working. This is the best way to reduce uncertainty in BMP effectiveness estimates.[158] Work on this front is ongoing in the Chesapeake Bay Program Partnership's Scientific Technical Assessment & Reporting (STAR) team, and this work should continue to be a priority.[159]
3. In the meantime, the Bay states must account for BMP uncertainties with meaningful margins of safety.

Each of these recommendations is discussed in more detail below.

6.1 Agricultural nutrient inputs should be reduced

The simplest way to reduce nutrient discharges is to reduce nutrient inputs. Growing crops only utilize a fraction of the nitrogen and phosphorus applied in manure or fertilizer: In the German Branch study cited above, crops were estimated to use 27% and 8% of nitrogen and phosphorus inputs, respectively.[160] This suggests that inputs can be reduced in a way that does not adversely affect crop yield. UMD experts, for example, observed that:

> Fertilizer applications are currently targeted to maximize crop yields under the best weather conditions, with little consideration for the environmental consequences of unused [nitrogen] and [phosphorus] when crop uptake of [nitrogen and phosphorus] is limited by droughts or floods. We suggest that farmers apply fertilizers at lower rates to match crop yields.[161]

These researchers specifically recommended increasing the number of nutrient applications but decreasing the size of each application, providing nutrients on a schedule that crops are better able to exploit.[162] The Maryland Department of Legislative Services made a similar recommendation, observing that "[p]rioritizing efforts to establish crop fertilization policies and technology that better control the application of nutrients, rather than subsequently absorbing excess nutrients with cover crops, may be a more efficient use of limited State resources."[163]

6.2 Sub-watershed monitoring

As discussed in section 4 of this report, monitoring data from upstream sub-watersheds dominated by agriculture are likely to be instrumental in explaining why model predictions of nutrient load reductions have not materialized. Rather than relying on modeling and mainly downstream monitors, Maryland and the other Bay states should focus resources on routine monitoring in headwaters and small agricultural watersheds. Although the existing monitoring network is extensive, and the Chesapeake Bay Program Partnership is routinely re-evaluating the network, there are still important gaps. And while we recognize that monitoring is inherently expensive, it is also something that should be a priority when modeling appears to be inadequate. As the Bay Program's STAC Committee recently observed:

> A new focus is needed in our collective monitoring strategies. There is a distinct difference between results monitored in a demonstration watershed and those expected from a larger geographic area. Funding is scarce for both experimentation and for additional monitoring, but the general public and legislators demand results and accountability.[164]

University of Maryland research in the Choptank River watershed, the ongoing research in Lycoming County, Pennsylvania, the Corsica River project discussed in section 5.2.6 above, and the research project designed by David Sligh in Appendix B of this report all provide useful examples of the kinds of projects that the Bay states can fund and/or implement to provide better assurances of TMDL progress.

6.3 Universities and/or the states should conduct field-testing of BMPs during both storm flow and base flow

Although there has been systematic research into the effect of some BMPs on nutrient loads in base flow, there has been less research done on the effects of BMPs on nutrient loads in storm flow.[165] This is an important avenue for future research. Studies of general hydrology and chemistry in the Choptank watershed show that 30% of nitrogen loads and 83% of phosphorus loads may travel in "quick flow."[166] As one UMD student observed, "[i]f storm discharges are not sampled, about 1/3 of the annual [nitrogen] load and almost all of the annual [phosphorus] load will be missed."[167]

Appendix B is an expert report, commissioned by EIP, that lays out one possible approach to field-testing of BMPs while accounting for both storm flow and base flow. David Sligh summarizes the need for storm flow monitoring, and then identifies a candidate location that is impaired for nutrients and sediments, dominated by agricultural land use, and in many ways ideal for water quality monitoring. He then proposes a monitoring plan, including a list of monitoring parameters, a monitoring schedule, and the type of equipment that would be needed.

One of the keys to an affordable storm flow monitoring program is a water sampling technology that can be left in place, but 'turn on' only during storm events. Appendix B suggests the use of ISCO automatic samplers and triggers that started the sampling cycle when a stream rises above a certain level. Antti Koskelo, a Master's student at the University of Maryland, used the same approach, with a pre-programmed ISCO 3700 sampler and an ISCO 1640 liquid level actuator as a trigger.[168]

Another key to a successful monitoring project will be complete information about BMP practices in the subwatershed being monitored. The author of Appendix B was able to identify poultry houses and recipients of conservation funds in the watershed that he proposed to study, but more precise information would allow a direct comparison between water quality monitoring and modeling using Bay Model BMP effectiveness estimates (see section 6.5 below).

Researchers at the University of Maryland are currently monitoring storm flow, in addition to ingoing baseflow monitoring, and will be looking for relationships between BMP implementation and both pathways. We recommend that the Bay states build on this model for more comprehensive field testing.

6.4 Universities and/or states should monitor the effectiveness of other BMPs and groups of BMPs

As the preceding sections of the report show, most BMPs have not been studied at the watershed scale. In order to reduce the uncertainty around the effectiveness of a BMP, the performance of that BMP will have to be assessed with real data, including in-stream water monitoring data, under real, variable conditions. This kind of monitoring would provide scientifically valuable information, and would also have immediate policy implications: The EPA expects nonpoint nutrient credits to be sold with a 2:1 uncertainty ratio, but will accept lower ratios if there is "direct and representative monitoring" "at a level similar to that performed at traditional NPDES point sources."[169]

6.5 The Bay states should make better use of farm-level BMP implementation data

With the right information, it would be possible to make direct comparisons between nutrient load predictions from field- and watershed-scale modeling and actual water quality data. The Maryland Department of Agriculture, for example, has developed a Nutrient Trading Tool that predicts nitrogen and phosphorus loads at the level of individual farm fields, using annual cropping and fertilization data as inputs.[170] Although the tool was originally developed to estimate nutrient credits, a variant of the tool will likely also be used to evaluate farms seeking certification under Maryland's agricultural certainty program. It is therefore possible to predict field-level nutrient loads before and after BMP implementation. It should also be possible to model loads from every field in a sub-watershed, for example the German Branch watershed discussed above, and compare predicted water quality to actual water quality. This would not directly measure the success of any one BMP, but it would provide a quantitative assessment of how well the BMPs were collectively performing.

It is difficult to make use of field-scale land use data in Maryland at present, however, because the information is confidential and available only to the Maryland Department of Agriculture. There are two paths forward – either state agencies can make land use information accessible to organizations that collect water monitoring data, or state agencies can collect water monitoring data to verify their own nutrient load predictions. Either scenario would represent an important step forward. We have the capacity to measure water quality in sub-watersheds dominated by agriculture (as proposed in Appendix B), and we have the capacity to predict water quality in these same sub-watersheds using available land use information. All that remains is to compare the two and evaluate how well the BMPs are working. Here it is important to note that the experimental designs cited by the Bay Program and others as good case studies have had the benefit of this kind of information.[171]

6.6 The Bay states must apply meaningful margins of safety in the absence of better information

All of the foregoing research recommendations may help to reduce BMP uncertainty over the long term. In the short term, however, given the large uncertainties in nonpoint loadings and BMP effectiveness, the Bay states must apply robust margins of safety or uncertainty ratios.

The Clean Water Act requires TMDLs to include "reasonable assurances" that they will achieve necessary load reductions. As discussed above, many policies being implemented by the Bay states depend on agricultural BMPs for their success, and the limited available field research suggests that BMPs are not working as well as they were expected to. This means that farmers may be immunized from future regulations by agricultural certainty programs even though they are discharging nutrients at levels greater than baseline. It also means that nutrient trading programs are likely to lead to net increases in nutrient loads. In order to avoid these outcomes, the Bay states must acknowledge that they are less than 100% certain about how well the BMPs are working in the field. Robust margins of safety, or uncertainty ratios in the trading context, will ensure that even if BMPs underperform, TMDL goals will still be met.

[1] U.S. EPA, Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment, 1-3 – 11-11 (Dec. 19, 2010) (summarizing pre-TMDL history of Chesapeake Bay restoration efforts) (hereinafter "TMDL").

[2] *Id*. at ES-3.

[3] *Id*. at 2-7 – 2-8.

[4] Under the Clean Water Act, water bodies are defined as impaired at the state level, when they exceed state water quality standards. 33 U.S.C. § 1313(d)(1)(A).

[5] TMDL, *supra* note 1, at 2-14.

[6] These include "migratory fish spawning and nursery," "shallow-water bay grass," "open-water fish and shellfish," "deep-water seasonal fish and shellfish," and "deep-channel seasonal refuge." *Id*. at 3-4.

[7] *Id*. at 3-2 – 3-14. The TMDL variously describes a criterion for water clarity and submerged aquatic vegetation as simply "water clarity" (*see, e.g.*, *id*. at 3-18) or "submerged aquatic vegetation (SAV)/water clarity," (*see, e.g.*, *id*. at 6-2), but states that "SAV acreage is the primary [Water Quality Standard]." (*Id*. at 6-42). The TMDL does define separate standards for water clarity (in units of "Secchi Depth") and aquatic vegetation (in units of acreage goals and application depths). (*Id*. at 3-12).

[8] *See generally id*. at Section 5.

[9] Chesapeake Bay Program (CBP), Modeling, https://www.chesapeakebay.net/about/programs/modeling/.

[10] *See generally* TMDL, *supra* note 1, at Sections 6 and 8.

[11] *Id*. at Section 8.

[12] *Id*. at 4-29.

[13] Data from CBP, Water Quality: TMDL tracking, http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=2

[14] CBP, http://www.chesapeakebay.net/track/health.

[15] UMCES, Chesapeake Bay Report Card, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/.

[16] *Id*. at http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/faq/.

[17] CBP, Nitrogen, Phosphorus, and Sediment loads to the Bay, http://www.chesapeakebay.net/track/health/factors.

[18] CBP, Reducing Nitrogen, Phosphorus, and Sediment pollution, http://www.chesapeakebay.net/track/restoration.

[19] CBP, Sediment loads to the Bay, http://www.chesapeakebay.net/indicators/indicator/sediment_loads_and_river_flow_to_the_bay.

[20] The TMDL allocations for nitrogen, phosphorus, and sediment are 201.6 million pounds, 12.5 million pounds, and 6.5 billion pounds, respectively. The Bay Program's 2025 targets for these pollutants are 207.6 million pounds, 14.5 million pounds, and 7.3 billion pounds. These targets are 3%, 16%, and 14% higher than TMDL allocations for nitrogen, phosphorus, and sediment, respectively. CBP, Reducing Nitrogen, Phosphorus, and Sediment pollution, http://www.chesapeakebay.net/track/restoration.

[21] *Id*.

[22] UMCES, total nitrogen indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/total_nitrogen/#_Trends_Graph.

[23] UMCES, Total phosphorus indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/total_phosphorus/#_Trends_Graph.

[24] D.L. Moyer et al., Comparison of Two Regression-Based Approaches for Determining Nutrient and Sediment Fluxes and Trends in the Chesapeake Bay Watershed (2012).

[25] R.M. Hirsch et al., Determining Nutrient and Sediment Loads and Trends in the Chesapeake Bay Watershed by Using an Enhanced Statistical Technique (Jan. 2013).

[26] Moyer et al., *supra* note 24, at 12.

[27] *See, e.g.*, U.S. Global Change Research Program, Climate Change Impacts in the United States: The Third National Climate Assessment, 9 (2014) (showing a 71% increase in "the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012" for the northeast region, which includes all of the Bay states other than Virginia, and showing a 27% increase in the southeast region, which includes Virginia).

[28] Moyer et al., *supra* note 24, at 2 ("[T]he majority (85 percent) of total nitrogen load, nitrate, and orthophosphorus combinations exhibited long-term (1985 to 2010) trends in [] flow-normalized flux [loads] that indicate improvement or reduction in associated flux and the majority (83 percent) of the total phosphorus (from 1985 to 2010) and suspended sediment (from 2001 to 2010) combinations exhibited trends in [] flow-normalized flux that indicate degradation or increases in the flux delivered.").

[29] *Id*. at 41.

[30] *Id*. at 44.

[31] *Id*. at 50.

[32] *Id*. at 48.

[33] CBP, http://www.chesapeakebay.net/indicators/indicator/dissolved_oxygen.

[34] UMCES, Dissolved Oxygen indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/dissolved_oxygen/#_Threshold_Map. Unlike the Chesapeake Bay Program results, the UMCES results are not broken out by designated use.

[35] CBP, Chlorophyll *a* Indicator, Analysis and Methods File, http://www.chesapeakebay.net/indicators/indicator/chlorophyll_a.

[36] UMCES, Chlorophyll a Indicator, Threshold Levels, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/chlorophyll_a/#_Threshold_Levels.

[37] UMCES, Chlorophyll a Indicator, Threshold Map, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/chlorophyll_a/#_Threshold_Map.

[38] CBP, Water Clarity Indicator, http://www.chesapeakebay.net/indicators/indicator/water_clarity.

[39] UMCES, Water Clarity indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/water_clarity/#_Threshold_Map.

[40] UMCES, Aquatic Grasses trend, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/aquatic_grasses/#_Trends_Graph.

[41] CBP, Bottom Habitat Indicator, http://www.chesapeakebay.net/indicators/indicator/bottom_habitat.

[42] UMCES, Benthic Index, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/benthic_index/#_Trends_Graph.

[43] UMCES, Bay Health Index, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/bay_health_index/#_Trends_Graph. The seven indicators are chlorophyll a, dissolved oxygen, water clarity, total nitrogen, total phosphorus, aquatic grasses, and benthic biological integrity.

[44] CBP, ChesapeakeStat, http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=5.

[45] CBP, ChesapeakeStat, Water Quality: 2009-2011 Milestones, http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=4

[46] U.S. EPA, Evaluation of Maryland's 2012-2013 and 2014-2015 Milestones (June 26, 2014), http://www.epa.gov/reg3wapd/tmdl/2014Evaluations/MD.pdf.

[47] U.S. EPA, Evaluation of Pennsylvania's 2012-2013 and 2014-2015 Milestones (June 26, 2014), http://www.epa.gov/reg3wapd/tmdl/2014Evaluations/PA.pdf.

[48] Data downloaded from CBP, Reducing Pollution, http://www.chesapeakebay.net/track/restoration.

[49] USDA, Impacts of Conservation Adoption on Cultivated Acres of Cropland in the Chesapeake Bay Region, 2003-06 to 2011, 5 (Nov. 2013).

[50] For example, the Maryland Department of Agriculture estimated that net nitrogen and phosphorus loads from agriculture increased between 2011 and 2012, due in part to an increase in animal populations and a decrease in compliance with Nutrient Management Plans. Maryland Department of Agriculture, Maryland's TMDL Process and the Role for Agriculture – WIP Phase II Summary (April/May 2013), http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/Regional_Meetings/Spring2013/Agricultural_Progress_and_Assistance.pdf.

[51] See Figures 1, 2, and 3 of this report.

[52] *See, e.g.*, Table 1 above, showing absolute nitrogen and phosphorus reductions from wastewater sources of 11.1 million pounds and 1.1 million pounds, respectively.

[53] USDA, *supra* note 49, at 5.

[54] *Id*. at 8.

[55] U.S. Global Change Research Program, *supra* note 27, at 9 (2014) (showing a 71% increase in "the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012" for the northeast region, which includes all of the Bay states other than Virginia, and showing a 27% increase in the southeast region, which includes Virginia).

[56] STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee), Incorporating Lag-Times into the Chesapeake Bay Program. STAC Publ, #13-004, 8 (2013).

[57] *See generally id*.

[58] *Id* at 22.

[59] Trust Fund Evaluation Workgroup, 2010 Trust Fund Water Quality Monitoring Strategy, 12 (2010) (hereinafter "2010 Trust Fund Strategy").

[60] W.E. Sanford and J.P. Pope, *Quantifying Groundwater's Role in Delaying Improvements to Chesapeake Bay Water Quality*, 47 ENVIRON. SCI. TECHNOL. 13330, 13332 (2013).

[61] A. Sutton et al., *Effects of restored stream buffers on water quality in non-tidal streams in the Choptank river basin*, 208 WATER AIR SOIL POLLUT. 101, 103 (2010).

[62] Maryland StateStat, BayStat, https://data.maryland.gov/browse?tags=baystat.

[63] USGS, monthly and annual load data for station 1491000 in Greensboro, MD, http://cbrim.er.usgs.gov/load_reports.html.

[64] USGS station 1491000 has latitude and longitude coordinates of 38.99722, -75.7861. Station ET5.0 has coordinates of 38.99718, -75.7864. CBP, Water Quality Database (1984-present), http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present.

[65] Land use in the sub-basin above ET5.0 is roughly 49% agriculture. T. Fisher et al., *The Choptank Basin in Transition: Intensifying Agriculture, Slow Urbanization, and Estuarine Eutrophication*, in COASTAL LAGOONS: CRITICAL HABITATS OF ENVIRONMENTAL CHANGE 135, 140 (M.J. Kennish and H.W. Paerl, eds., 2010) (showing land use for the "USGS (Greensboro)" subbasin).

[66] Maryland Department of Natural Resources, Nontidal Networking Program, Nutrient and Sediment Trend Monitoring, Quality Assurance Project Plan (July 2005 – June 2006), http://www.dnr.state.md.us/irc/docs/00013648.pdf.

[67] BayStat, *supra* note 62.

[68] *Id*.

[69] *Id*. 2017 targets were not calculated for sediment at the scale of the Choptank River.

[70] EIP extracted annual data for 1985-2011; although the USGS dataset also includes data for 1984 and 2012, these years did not appear to have 12 months of coverage. USGS, monthly and annual load data for station 1491000 in Greensboro, MD, http://cbrim.er.usgs.gov/load_reports.html.

[71] *Id*.

[72] *Id*.

[73] *Id*.

[74] Concentrations of nitrogen, phosphorus, and sediment were often systematically higher or lower in bottom-layer water, but temporal trends were generally consistent between the two layers (data not shown here).

[75] Data extracted by EIP from the Chesapeake Bay Program database and averaged on an annual basis for shallow water samples, then averaged on a 3-year rolling basis. CBP, Water Quality Database (1984-present), http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present. For Station ET5.0, total nitrogen was reported as "TN" for the years 2006-2012 only. From 1986-2005, "TN" was not reported. Following Bay Program protocols, EIP calculated total nitrogen for 1986-2005 as nitrate and nitrite (NO23W) plus total Kjeldahl nitrogen whole (TKNW). CBP, Guide to Using Chesapeake Bay Program Water Monitoring Data, 70 (Feb. 1, 2012).

[76] Land use in the sub-basin above ET5.0 is roughly 49% agriculture. Fisher, *supra* note 65, at 140 (showing land use for the "USGS (Greensboro)" subbasin). Land use in the Choptank basin as a whole is 62% agriculture. Sutton et al., *supra* note 61, at 103.

[77] Sutton et al., *supra* note 61, at 105.

[78] This is the average volume-weighted total nitrogen concentration of 15 sub-basin monitoring stations, each of which was sampled monthly between January 2003 and December 2006. *Id*. at 109.

[79] *Id*. at 111.

[80] USGS station 1491000 has latitude and longitude coordinates of 38.99722, -75.7861. Station ET5.0 has coordinates of 38.99718, -75.7864. CBP, Water Quality Database (1984-present), http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present.

[81] See also Moyer et al., *supra* note 24, at 39 (showing a 33% increase in flow-normalized load since 1985, and a 10% increase since 2000).

[82] Data extracted by EIP from the Chesapeake Bay Program database and averaged on an annual basis for shallow water samples, then averaged on a 3-year rolling basis. CBP, Water Quality Database (1984-present), http://www.chesapeakebay.net/data/downloads/cbp_water_quality_database_1984_present.

[83] *Id*.

[84] M. Zimmerman et al., Lycoming County Farm Project, 2013 Update (June 24, 2013).

[85] T. Simpson and S. Weammert, Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed, 5 (University of Maryland Mid-Atlantic Water Program, Dec. 2009).

[86] *Id*.

[87] U.S. EPA, Chesapeake Bay Phase 5.3 Community Watershed Model, Section 6 (Dec. 2010), http://www.chesapeakebay.net/about/programs/modeling/53.

[88] Simpson and Weammert, *supra* note 85.

[89] *See, e.g.*, Chesapeake Bay Program Water Quality Goal Implementation Team, Protocol for the Development, Review, and Approval of Loading and Effectiveness Estimates for Nutrient and Sediment Controls in the Chesapeake Bay Watershed Model (Mar. 15, 2010), http://www.chesapeakebay.net/documents/Nutrient-Sediment_Control_Review_Protocol_07162013.pdf.

[90] *See, e.g.*, U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-4; U.S. EPA Region III, Technical Memorandum: Accounting for Uncertainty in Offset and Trading Programs, 6 (Feb. 12, 2014) (hereinafter "EPA Technical Memorandum").

[91] Although not a focus of this report, the Chesapeake Bay Program Partnership has made an effort to increase verification of BMP implementation. *See, e.g.*, Chesapeake Bay Program partnership BMP Verification Committee, http://www.chesapeakebay.net/groups/group/best_management_practices_bmp_verification_committee.

[92] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-5.

[93] *See, e.g.*, National Research Council (NRC), Achieving Nutrient and Sediment Reduction Goals in the Chesapeake Bay: An Evaluation of Program Strategies and Implementation, 76 (2011) ("[C]redited BMP efficiencies have more commonly been decreased rather than increased in the light of new field information.").

[94] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-9.

[95] Simpson and Weammert, *supra* note 85, at 114.

[96] U.S. EPA Chesapeake Bay Model, supra note 87, at 6-3. *See also* EPA Technical Memorandum, *supra* note 90, at 8 ("The process used to develop the CBP partnership BMP effectiveness values is designed to arrive at unbiased and realistic values . . . [Adjustments to remove bias] generate BMP effectiveness values that are unbiased and realistic but not necessarily conservative.").

[97] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-7 – 6-12; EPA Technical Memorandum, *supra* note 90, at 7 – 8.

[98] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-9.

[99] NRC, supra note 93, at 73.

[100] A. Sutton, *Evaluation of agricultural nutrient reductions in restored riparian buffers*, Ph.D. Thesis, University of Maryland, College Park, 137 – 138 (2006).

[101] *See, e.g.*, E.A. Dayton et al., *Demonstrating the relationship between soil phosphorus measures and phosphorus solubility: Implications for Ohio phosphorus risk assessment tools*, J GREAT LAKES RES, 4 (in press, 2014) (demonstrating "an inflection point in soil P saturation, beyond which P solubility increases more rapidly").

[102] *See, e.g.*, A. Sutton et al., *Historical Changes in Water Quality at German Branch in the Choptank River Basin*, 199 WATER AIR SOIL POLLUT. 353, 361 (2009) (showing higher phosphorus concentrations in stormflow than in baseflow, and higher nitrogen concentrations in baseflow than in stormflow); Sutton, *supra* note 100, at 5 ("Nitrate is water-soluble and moves to streams primarily via groundwater contribution to base flow."); *id*. at 163 (finding, in two subwatersheds, that 70-85% of nitrogen moved in baseflow while 55-70% of phosphorus moved with stormflow).

[103] Sutton et al. 2010, *supra* note 61 at 115.

[104] Sutton, *supra* note 100, at 5 – 7.

[105] *Id*. at 9.

[106] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-24.

[107] *Id*. at 6-25.

[108] Sutton, *supra* note 100, at 15.

[109] The study authors did not differentiate between grass and forest buffers based on research suggesting that the two types of buffers have similar effects on nutrients. *Id*. at 101 – 102.

[110] Sutton et al. 2010, *supra* note 61, at 106.

[111] *Id*.

[112] *Id*. at 101, 112; Sutton, *supra* note 100, at 119.

[113] Sutton et al. 2010, *supra* note 61, at 111.

[114] *Id*. at 112.

[115] *Id*.

[116] *Id*. at 116.

[117] Sutton, *supra* note 100, at 129.

[118] The underlying nitrogen model calculated the regression between 2003-06 flow-weighted total nitrogen concentrations and the percentage of each subwatershed in agricultural land cover using data from Sutton et al. 2010, *supra* note 61, Tables 2 and 3.

[119] The phosphorus model regressed 2003-06 flow-weighted total phosphorus concentrations against the percentage of each subwatershed in agricultural land cover using data from Sutton et al. 2010, *supra* note 61, Tables 2 and 3.

[120] Sutton et al. 2010, *supra* note 61, at 111 – 112.

[121] Sutton, *supra* note 100, at 161 – 165 (finding twice as much phosphorus leaving the less-buffered subwatershed, and significantly greater volume-weighted particulate and dissolved phosphorus concentrations in the less-buffered watershed).

[122] *Id*.

[123] *See* U.S. EPA Chesapeake Bay Model, *supra* note 86, at 6-34; Simpson and Weammert, *supra* note 85, at 97; Fisher et al., *supra* note 65, at 155.

[124] Simpson and Weammert, *supra* note 85, at 103.

[125] *Id*. at 104.

[126] *Id*. at 116 – 117.

[127] C.M. Lyerly et al., New Insights: Science-based evidence of water quality improvements, challenges, and opportunities in the Chesapeake, 14 – 15 (Feb. 2014) (hereinafter "New Insights"); K.W. Staver and R. B. Brinsfield, Assessing the Impact of Changes in Management Practices on Nutrient Transport from Coastal Plain Agricultural Systems (Aug. 1995).

[128] Simpson and Weammert, *supra* note 85, at 114.

[129] Fisher et al., *supra* note 65, at 155 – 157.

[130] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-29.

[131] *Id*. at 6-30, Simpson and Weammert, *supra* note 85, at 69.

[132] Fisher et al., *supra* note 65, at 152.

[133] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-23.

[134] Fisher et al., *supra* note 65, at 152.

[135] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-39 – 6-41.

[136] D.G. Galeone et al., Effects of Streambank Fencing of Pasture Land on Benthic Macroinvertebrates and the Quality of Surface Water and Shallow Groundwater in the Big Spring Run Basin of Mill Creek Watershed, Lancaster County, Pennsylvania, 1993-2001 (USGS Scientific Investigations Report 2006-5141, 2006).

[137] Id. at 1.

[138] Id. at 64.

[139] U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-41 (effectiveness estimates vary geographically).

[140] New Insights, *supra* note 127, at 15; 2010 Trust Fund Strategy, *supra* note 59, at 13 – 16.

[141] Sutton et al. 2009, *supra* note 102, at 355 (defining the area as being 52 km^2 with 72% agricultural land use in 2000).

[142] *Id*. at 359.

[143] *Id*. at 362.

[144] *Id*. at 361-62.

[145] Fisher et al., *supra* note 65, at 148. *See also* Sutton, *supra* note 99, at 199 (estimating that 65% of the groundwater in the German Branch watershed would have been replaced between the early 1990s and the early 2000s).

[146] Sutton et al. 2009, *supra* note 102, at 359; Fisher et al., *supra* note 64, at 159.

[147] Fisher et al., *supra* note 65, at 148.

[148] 2010 Trust Fund Strategy, supra note 59, at 21 – 25.

[149] New Insights, *supra* note 127, at 29 – 31; see also Corsica River Targeted Intiative, Progress Report: 2005-2011 (2011).

[150] See VA Code § 10.1-104.7, 104.8 (Virginia Resource Management Plan statute); 4 VAC 50-70 (Virginia Resource Management Plan regulations); Maryland Code, Agriculture, Title 8, Subtitle 10 (Maryland agricultural certainty statute); Chesapeake Bay Commission, Comparison of Agricultural Certainty Program Design in Maryland and Viriginia (Apr. 15, 2013), available at http://www.agandruralleaders.org/LAC/2013/materials/breakout_1/Swanson-Ag_Certainty_MD_VA.pdf (providing a side-by-side comparison of the two programs).

[151] See VA Code § 10.1-104.8 ("The regulations shall . . . Include agricultural [BMPs] sufficient to implement the Virginia Chesapeake Bay TMDL Watershed Implementation Plan and other local [TMDL] requirements."); Maryland Code, Agriculture, § 8-1004 ("An agricultural operation may be certified as meeting the requirements of the Program if the agricultural operation is determined by the Department to meet . . . agricultural nitrogen, phosphorus, and sediment loads necessary for the agricultural operation to meet [the Bay TMDL, the watershed implementation plan, any local TMDL, and other requirements].").

[152] The margin of safety was in the form of a requirement that participating farmers demonstrate "a 10% to 20% addition [sic] nutrient reduction beyond TMDL baseline."). Maryland Department of Agriculture, Creating a Certainty Program for Producers by Utilizing an On-Farm Nutrient Assessment and BMP Credit Tool Consistent with the Maryland Watershed Implementation Plan (2012).

[153] Maryland Department of Legislative Services, Office of Policy Analysis, *Chesapeake Bay Restoration Strategies: Agricultural Certainty, Cover Crops, and Nutrient Trading* 7 (Nov. 2013) (emphasis added).

[154] *See* World Resources Institute, WRI Fact Sheet: Comparison Tables of State Nutrient Trading Programs in the Chesapeake Bay Watershed (May 2011), available at: http://www.wri.org/sites/default/files/comparison_tables_of_state_chesapeake_bay_nutrient_trading_programs.pdf; U.S. EPA Region III, Chesapeake Bay TMDL: Trading and Offsets, http://www.epa.gov/reg3wapd/tmdl/ChesapeakeBay/EnsuringResults.html?tab2=7.

[155] EPA Technical Memorandum, *supra* note 90, at 4.

[156] *See* World Resources Institute, *supra* note 154, at 10.

[157] Maryland Department of Legislative Services, *supra* note 153, at 19.

[158] *See, e.g.*, U.S. EPA Chesapeake Bay Model, *supra* note 87, at 6-12 ("Better research on demonstration and monitoring of BMP, system, and small watershed conservation effects will increase confidence in BMP effectiveness.").

[159] *See generally*, Chesapeake Bay Program Partnership Scientific Technical Assessment and Reporting, http://www.chesapeakebay.net/groups/group/scientific_and_technical_analysis_and_reporting. Note that the Chesapeake Bay Program Partnership has recently been struggling with fiscal constraints on their ability to sustain the existing monitoring network. Chesapeake Bay Program Partnership, Building and Sustaining Integrated Networks, http://www.chesapeakebay.net/groups/group/building_and_sustaining_integrated_networks_basin ("The Chesapeake Bay Program Partnership's water quality monitoring program was under budgetary pressures in 2013 resulting in a 945K funding gap to sustain the CBP tidal and nontidal monitoring networks.").

[160] Sutton, *supra* note 100, at 202.

[161] Fisher et al., *supra* note 65, at 161.

[162] *Id*.

[163] Maryland Department of Legislative Services, *supra* note 153, at 13.

[164] STAC 2013, *supra* note 56, at 21.

[165] "[M]ost nutrient monitoring programs do not sample at short intervals during storm events." A. Koskelo, *Hydrologic and Biogeochemical Storm Response in Choptank Basin Headwaters*, Master's Thesis, University of Maryland, College Park, 112 (2008); "[S]torm flow is rarely sampled adequately in monitoring programs." Fisher et al., *supra* note 65, at 148.

[166] As measured in four subwatersheds over 15 months. Koskelo, *supra* note 165, at 109 and 180. Quick flow is defined as "non-baseflow" and includes "(1) direct precipitation onto the stream channel and nearby saturated areas, (2) overland flow, . . . (3) shallow subsurface stormflow, . . . and (4) groundwater flow."). A. Koskelo et al., A New Precipitation-based Method of Baseflow Separation and Event Identification for Small Watersheds (<50 km^2), 450-451 J. Hydrol. 267 (2012).

[167] Koskelo, *supra* note 165, at 182 – 183.

[168] *Id*. at 119.

[169] EPA Technical Memorandum, *supra* note 90, at 5 (the memorandum also suggests that monitoring would be adequate if it met "the expectations described in EPA's forthcoming Representative Sampling technical memorandum."). *Id*. at 10.

[170] Maryland Department of Agriculture, Nutrient Trading Tool, http://www.mdnutrienttrading.com/.

[171] *See, e.g.*, the Upper Pocomoke watershed case study: 2010 Trust Fund Strategy, *supra* note 59, at 13 ("Crop type, nutrient application rates, yield data, and soil test results were collected directly from farm operators or crop consultants working in the treatment and control watersheds.").

Appendix A: Chesapeake Bay TMDL progress indicators

Figure A-1: Attainment of Dissolved Oxygen criteria in four designated use areas.[172]

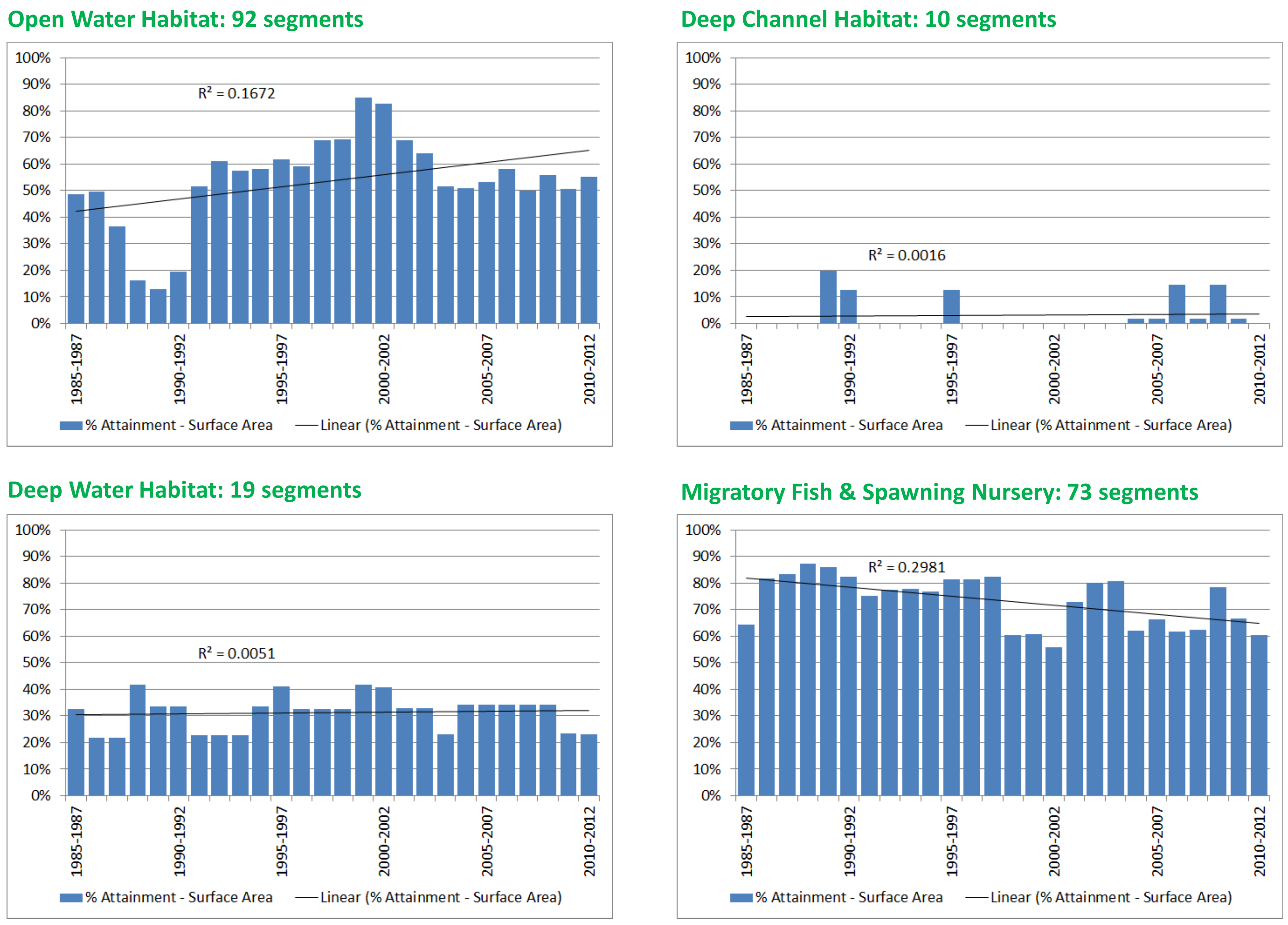


Figure A-2: UMCES chlorophyll *a* score for the Overall Bay, 1986-2012[173]

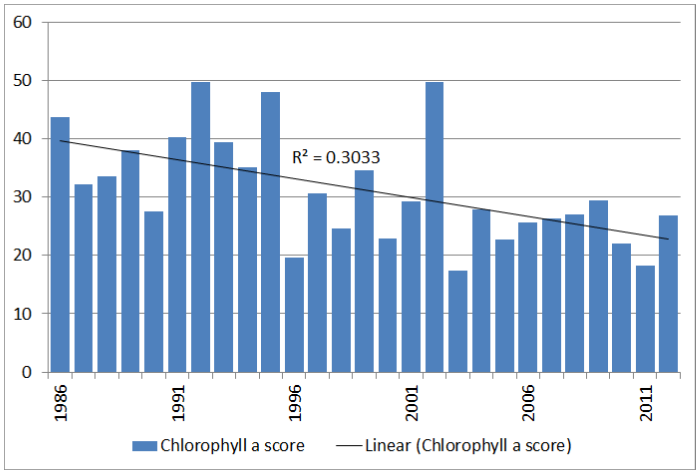


Figure A-3: Chesapeake Bay Program water clarity attainment[174]

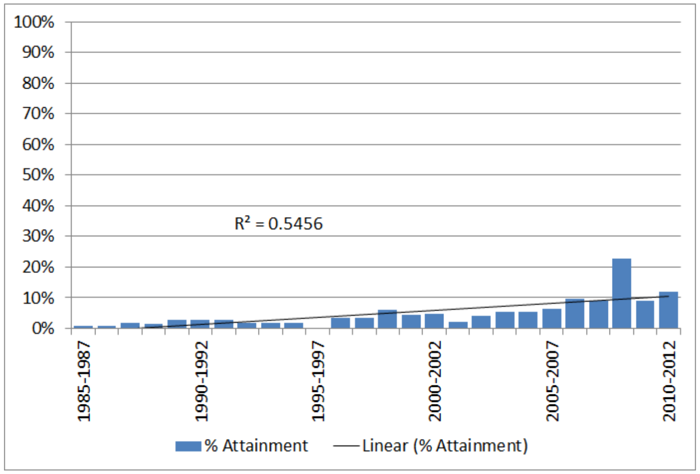


Figure A-4: UMCES water clarity score[175]

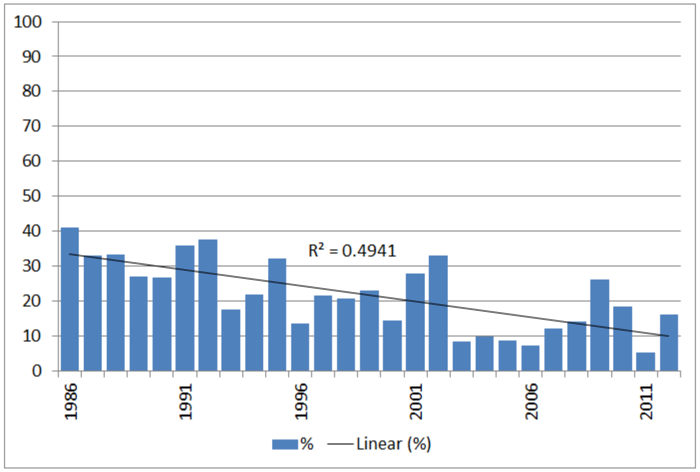


Figure A-5: Chesapeake Bay Program aquatic vegetation acreage[176]

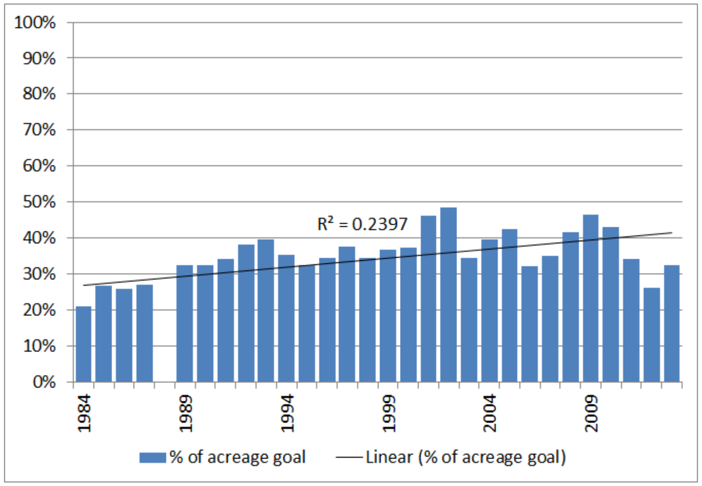


Figure A-6. Chesapeake Bay Program, % of Bottom Habitat Goal Achieved[177]

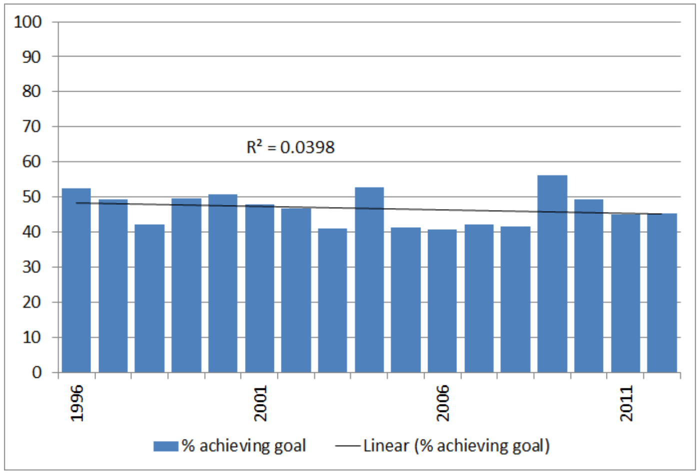
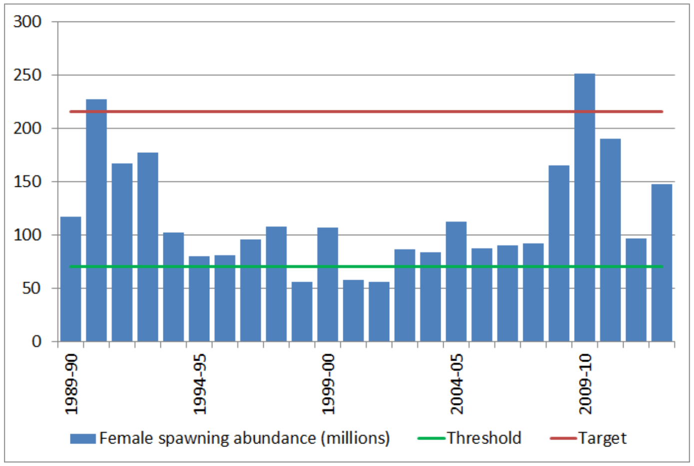
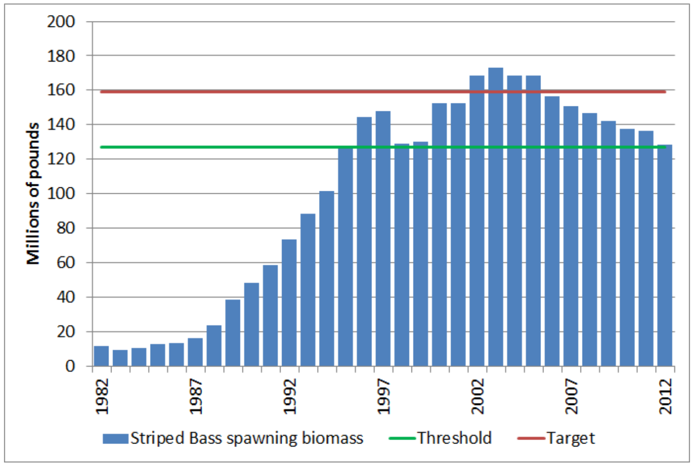


Figure A-7. Species abundance data from the Chesapeake Bay Program[178]

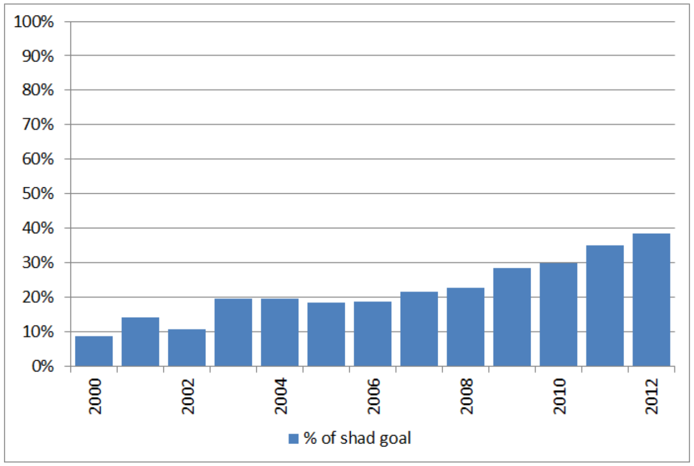
Blue crab abundance



Striped Bass female spawning stock biomass



Shad returning to Chesapeake Bay



Juvenile Menhaden abundance

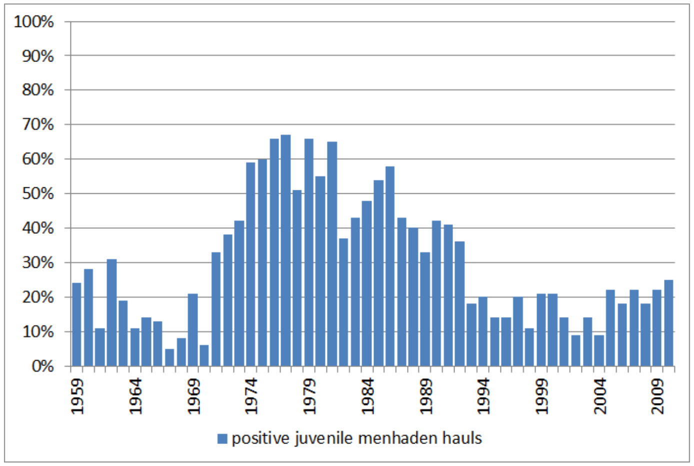


Figure A-8. UMCES nitrogen score for Chesapeake Bay waters[179]

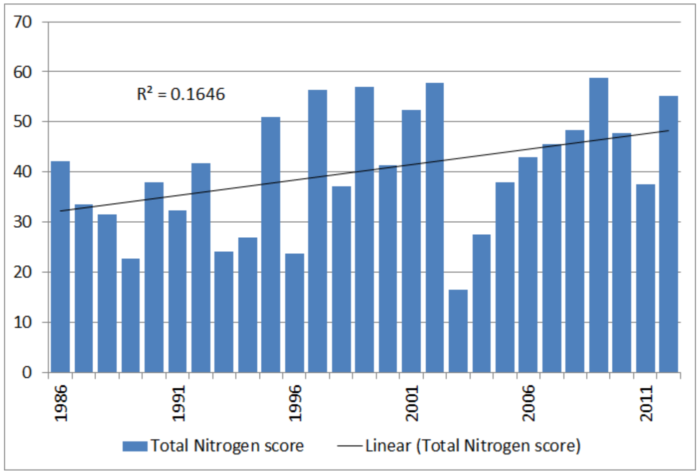


Figure A-9. UMCES phosphorus score for Chesapeake Bay waters[180]

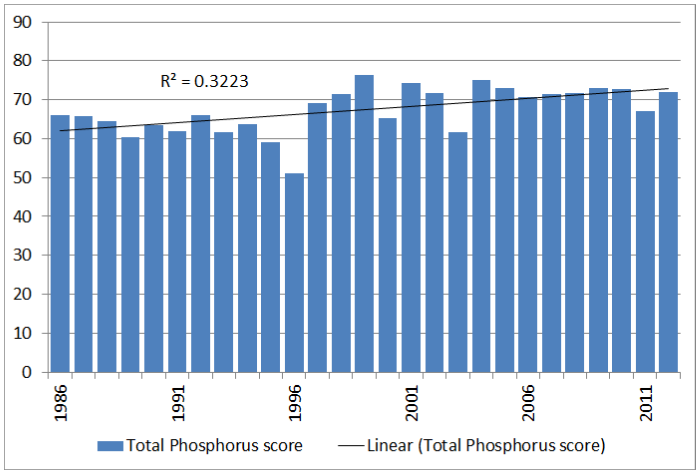


Figure A-10. Chesapeake Bay Program combined water quality standards indicator[181]

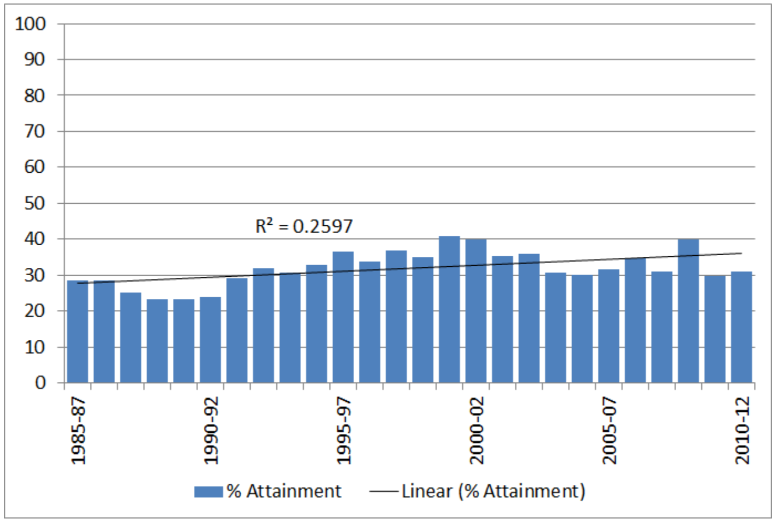


Figure A-11. UMCES Bay Health Index[182]

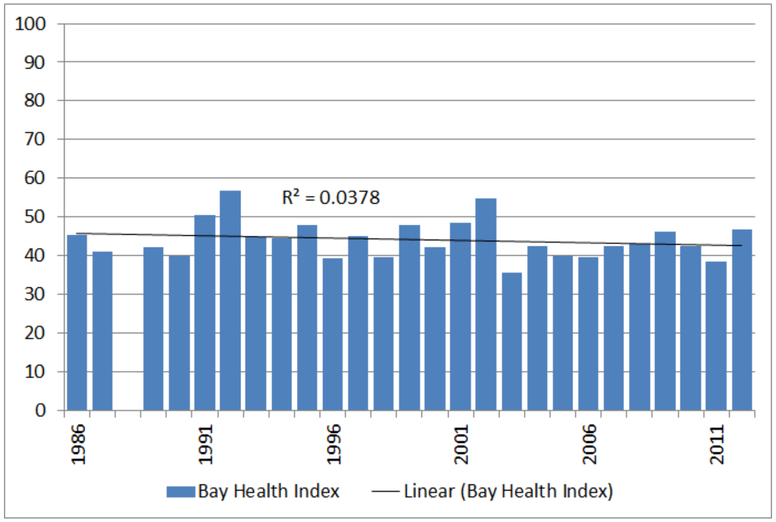


Table A-1: 2013 milestones - cumulative progress for sectors other than agriculture. Progress was calculated by dividing the 2013 progress for each practice by the 2013 milestone for the same practice.[183]

Urban/Suburban Practices	Unit	NY	PA	MD	VA	WV	DE	DC
Wet Ponds & Wetlands	acres		102%	123%	102%	113%	109%	73%
Dry Ponds	acres		101%	103%	107%		100%	105%
Extended Dry Ponds	acres		102%	119%	106%	103%	128%	97%
Infiltration Practices	acres		106%	128%	32%	552%	109%	132%
Filtering Practices	acres			152%	71%	134%	110%	123%
BioRetention	acres			830%			163%	45%
BioSwale	acres						147%	0%
Permeable Pavement	acres							
Vegetated Open Channel	acres							
SWM by Era (1985-2002)	acres			102%				
SWM by Era (2002-2010)	acres			100%				
Retrofit Stormwater Management	acres			103%				
Erosion and Sediment Control	acres	31%	56%	76%	63%	60%	83%	
Extractive Erosion and Sediment Control	acres							
Forest Conservation Act	acres			106%		100%		
Impervious Surface & Urban Growth Reduction	acres		90%		3966%	100%		107%
Urban Forest Buffers	acres			119%		118%		
Urban Tree Planting	acres		36%			116%	105%	173%
Urban Nutrient Management	acres			112%	48%	0%	7%	
Urban Phosphorus Legislation	% acres @ % TP reduction, acres							
Urban Stream Restoration (feet)	feet		179%	95%	449899%	100%	0%	111%
Street Sweeping (lbs)	lbs				1%	84%		
Street Sweeping	acres						0%	64%
Abandoned Mine Reclamation	acres		95%		151%	100%		
Septic Connections	systems		117%	160%	1%	117%	65%	
Septic Denitrification	systems			103%	259%	100%		
Septic Pumping	systems				68%	136%		
Resource Practices								
Forest Harvesting BMPs	acres		198%	98%	88%	101%	806%	
Dirt&Gravel Road E&S (feet)	feet		100%					

Table A-2: 2013 milestones - cumulative progress for agricultural practices. Progress was calculated by dividing the 2013 progress for each practice by the 2013 milestone for the same practice.[184]

Agriculture Practices	Unit	NY	PA	MD	VA	WV	DE	DC
Traditional+Enhanced Nutrient Application Management	acres	63%	40%	81%	154%	28%	81%	
Nutrient Application Management on Pasture	acres				25%		0%	
Enhanced Nutrient Application Management on Pasture	acres							
Conservation Tillage w/ Continuous NoTill	acres	86%	83%	102%	73%	82%	71%	
Commodity+Cover Crop	acres	8%	90%	115%	195%	69%	135%	
Pasture Management Composite	acres	88%	159%	105%	130%	112%	299%	
Forest Buffers on Fenced Pasture Corridor	acres	21%			100%	881%		
Grass Buffers on Fenced Pasture Corridor	acres	79%			62%			
Forest Buffers	acres	103%	73%	103%	89%	2%	70%	
Wetland Restoration	acres	99%	67%	100%	58%	50%	236%	
Land Retirement	acres	96%	63%	92%	109%	107%	80%	
Grass Buffers	acres	23%	76%	106%	96%	96%	47%	
Tree Planting	acres	90%	97%	94%	169%	106%	270%	
Carbon Sequestration	acres		98%	234%			0%	
Conservation Plans	acres	121%	109%	120%	123%	98%	94%	
Water Control Structures	acres			53%	3657%		0%	
Crop Irrigation Management	acres			0%			0%	
Liquid & Poultry Injection	acres			0%				
Ditch Filters	acres							
Capture & Reuse	acres			0%				
NonUrban Stream Restoration	feet	0%	107%	911%	589%	104%	11%	
Livestock+Poultry Waste Management Systems	AU	93%	106%	105%	102%	132%	78%	
Livestock+Poultry Mortality Composting	AU	780%	169%	103%	733%		117%	
Barnyard Runoff Control & Loafing Lot Management	acres	84%	144%	99%	257%	361%	24%	
Manure Transport	tons		161%	131%	562%	383%	29%	
Poultry Phytase	% AU @ % TP reduction	100%	100%	100%	100%	100%	100%	
Swine Phytase	% AU @ % TP reduction				0%		0%	
Dairy Precision Feeding TN	% AU @ % TN reduction	31%	10000%				0%	
Dairy Precision Feeding TP	% AU @ % TP reduction	31%	10000%				0%	
Ammonia Emission Reductions (Alum)	% AU @ % TN reduction			0%				
Ammonia Emission Reductions (Biofilters & Lagoon Covers)	% AU @ % TN reduction						0%	

[172] Surface area-weighted dissolved oxygen attainment data from CBP, http://www.chesapeakebay.net/indicators/indicator/water_quality_standards_achievement_for_dissolved_oxygen_surface_area_asses.

[173] UMCES, Chlorophyll a indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/chlorophyll_a/#_Trends_Graph

[174] This indicator specifically quantifies surface area-weighted attainment of water quality standards for water clarity/submerged aquatic vegetation. CBP, Water Clarity Indicator, http://www.chesapeakebay.net/indicators/indicator/water_clarity

[175] UMCES, water clarity indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/water_clarity/.

[176] CBP, Aquatic Vegetation Indicator, http://www.chesapeakebay.net/indicators/indicator/bay_grass_abundance_baywide

[177] CBP, Bottom Habitat Indicator, http://www.chesapeakebay.net/indicators/indicator/bottom_habitat.

[178] CBP, Bay Health, http://www.chesapeakebay.net/track/health/bayhealth (including links to various species abundance indicators).

[179] UMCES, total nitrogen indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/total_nitrogen/#_Trends_Graph.

[180] UMCES, Total phosphorus indicator, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/total_phosphorus/#_Trends_Graph.

[181] CBP, Water Quality Standards progress, http://www.chesapeakebay.net/indicators/indicator/achievement_of_chesapeake_bay_water_quality_standards

[182] UMCES, Bay Health Index, http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/bay_health_index/#_Trends_Graph.

[183] "2013 Progress on 2010" was divided by "2013 Milestone" for each practice with a non-zero milestone. ChesapeakeStat, Two-Year Milestones, http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=4.

[184] *Id*.

Appendix B: David Sligh, Water Quality Monitoring Plan to Assess Agricultural Impacts and Effectiveness of BMPs in Maryland (Dec. 20, 2013).

Water Quality Monitoring Plan to Assess Agricultural Impacts and Effectiveness of BMPs in Maryland

Submitted to the Environmental Integrity Project
December 20, 2013

By David Sligh

New Monitoring Strategies are Needed

The overall state of the Chesapeake Bay is determined by the cumulative results of thousands of activities occurring throughout the watershed and, therefore, the degree to which we are able to achieve improvements in the Bay's health will be determined by the effectiveness of thousands of small-scale corrective actions on the land. Further, it is imperative that while we concentrate on the Bay-wide picture we not ignore the health of the thousands of water bodies upon which local communities depend.

To be certain that local actions achieve the desired results we must have valid data to know how much and which pollutants flow into our water bodies due to certain activities. In this report, we concentrate on agricultural lands and practices because, as is widely acknowledged, these sources have a very large impact on local waters and the Bay. As the Chesapeake Bay Program notes:

> "Close to one-quarter of land in the Chesapeake Bay watershed is devoted to agricultural production. Agriculture is essential to all people: farms provide us with food and fiber, natural areas, and aesthetic and environmental benefits. But agriculture is also the single largest source of nutrient and sediment pollution entering the Bay. While conventional tillage, fertilizers and pesticides can be beneficial to crops, their excessive use can pollute rivers and streams, pushing nutrients and sediment into waterways." (CBP 2013)

Despite this focus on agriculture, we believe the kind of analysis proposed here is needed in other contexts as well. Also, this report focuses primarily on Maryland, though the need to better understand and account for agricultural pollution is present in the other Bay states.

We are obliged to agree with the National Research Council panel which studied Bay cleanup strategies, that measuring every farming activity that affects water quality in the region and verifying the effectiveness of every Best Management Practice ("BMP") that is implemented, in a manner that would yield reliable, site-specific data is simply not possible. (NRC 2011) However, we also agree with numerous commentators who have acknowledged the serious deficiencies in our understanding of agricultural pollution and the efficiency of BMPs. We fear that efforts and resources aimed at fixing our problems are, in some cases, being wasted.

Despite limitations which prevent us from applying the same level of monitoring to every agricultural discharge as we do with most municipal and industrial discharges, we can and must do more to bridge the gap between the overly-broad and indistinct picture now available and the real, on-the-ground details we need. As the NRC panel stated, "[t]argeted monitoring programs in representative urban and agricultural watersheds and subwatersheds would provide valuable data to refine BMP efficiency estimates, particularly at the watershed scale, and thereby improve

Watershed Model predictions" and added, "excessive reliance on models in lieu of monitoring can magnify rather than reduce uncertainties." (NRC 2011)

More tightly-focused information will help make the Bay water quality models more reliable. Perhaps more urgent, both federal and state regulators are making decisions as to the value of specific farmer's actions in regard to permitting cases now, and hopes and predictions expressed by some as to the promise and validity of pollutant trading activities are pinned to estimates of pollution reduction efficiencies which currently inspire little confidence.

Assessing water pollution impacts through monitoring can and must take many forms. The types of measurements taken and the timing of data collection must be suited to the nature of the environments to be characterized and to the kinds of questions one hopes to answer with the data. A vast body of information has been collected to characterize the Chesapeake Bay and its major tributaries and these data are very valuable for looking at relatively large-scale conditions in these water bodies and perceiving overall trends in water quality.

In most cases, these water quality data are collected on either regular schedules (e.g. monthly or bimonthly) or sporadically, with frequency and timing set according more to the capabilities of the samplers than to the characteristics of the environment to be assessed. Routine grab sampling may occur, by chance, during either base-flow conditions or at higher flows but fails to characterize pollution inputs during entire storm events. As discussed below, under certain conditions, a year's worth of predicted runoff pollution can wash from a site during just one storm or even from a short period during a storm event. Therefore, we cannot claim to account for true runoff pollution impacts unless sampling is done throughout storm events as well as during low flow periods.

In addition, sampling both during storm events and in dry periods is necessary to understand the various flow paths through which pollutants flow from the land and into streams. Differences in both concentrations and loadings of pollutants must be studied during a range of flow conditions to differentiate between contributions from groundwater and surface flows.

Another problem with much of the available data on Bay tributary streams is that they are collected by investigators from many different organizations, using a variety of methods, and from locations that are almost always best suited to characterize cumulative impacts of many activities scattered across large land areas. Again, this situation is understandable and, even with these factors, the routine sampling efforts provide valuable information. However, we assert that a protocol that ensures more consistency and a more complete and accurate picture of conditions at a smaller, sub-watershed scale must be developed if regulatory mandates are to be met and maximum water quality improvement are to be attained.

A number of researchers have made important contributions to our knowledge of local conditions in selected sub-watersheds in the Bay region and we draw upon both these models and ones from other regions to support the proposal offered in this paper. For example, Fisher and colleagues have made a rather intensive study of the Choptank River basin over a period of three decades, including both periodic grab sampling and storm sampling, like what we propose (see, e.g., Fisher et al. 2010; Sutton et al. 2009). These efforts must be increased and accelerated and we must develop reliable protocols by which individual monitoring project results are readily extrapolated to other sub-watersheds in the region.

Also, while it is imperative that monitoring focus on nutrients and sediment pollution, other pollutants that are present on farmlands throughout the watershed and in waterbodies are not routinely and systematically monitored. As discussed below, heavy metals, particularly arsenic and lead, are major pollutants in many agricultural areas, as are pesticides and other complex organic chemicals.

The Nature of Water Pollution Caused by Agricultural Operations

The difficulties in making valid assessments of the pollution impacts from farms are many. Unlike the more discrete and definable water pollution sources that have been more effectively monitored and controlled, like sewage treatment plants and factories, the factors causing variability of conditions from one agricultural operation to another come in many forms.

Some of the factors that cause uncertainty in estimating the pollution impacts from agriculture include

"variability in natural landscape conditions, degree of management, and spatial and temporal changes among BMPs and their location. Examples include precipitation, hydrology and geology, lag time between implementation of practices and full performance, and between implementation and observed water quality benefits." (Simpson and Weammert 2009)

Our focus in controlling agricultural pollution in the Bay region has been on nutrients, primarily nitrogen and phosphorous, and on sediments. As discussed below, we believe this view must be broadened, to assess the presence and impacts from a wider range of pollutants. But even with the current limited focus, the complexities of natural systems and the differences in farming activities from one place to another make it difficult to generalize about the nature and mechanisms of nutrient and sediment pollution from farming.

Despite these difficulties, some basic mechanisms by which pollutants on the land may reach water bodies and cause harm have been described. We must keep these findings in mind if we are to make valid assessments and monitor effectively. Some general observations that strengthen the need for the types of monitoring we propose are discussed below.

"Accumulated phosphorus in the soil can remain for decades after phosphorus additions have ceased. Legacy phosphorus in stream and Bay sediments can be a source to the overlying water for a number of years. . . . Legacy phosphorus can also be unpredictably released when hydrologic forces erode soils or resuspend sediments." (NRC 2011, citing Cox et al. 1981 and Sharpley et al. 2009) Because of the long residence time of phosphorous in aquatic systems, we may not be able to discern changes in affected water bodies even though reduced inputs from small drainages or even individual farms have occurred. Sampling on a smaller scale may help us better target sites that need corrective actions the most.

Because less than 50 percent of the nitrogen introduced into agricultural systems is incorporated into crops (Smil, 1999; Cassman et al. 2002), large quantities can be discharged into aquatic systems. Often this occurs through infiltration to groundwater which feeds streams directly. Indeed, in some systems groundwater is the predominant source of nitrogen to surface waters. (NRC 2011) Where this is the case, we may see the highest nitrogen concentrations during periods of base flow rather than during storm events. (Fisher 2010) In other systems though, we may measure the highest values for both pollutant concentrations and loadings of nitrogen during storm sampling, indicating that large amounts of nitrogen reach surface waters through surface runoff. These varying conditions can be detected best by using a mixture of storm sampling and dry period sampling and, in fact, may be missed altogether without both.

A confounding factor that causes difficulty in perceiving large-scale improvements in nitrogen in the Bay and large tributaries after nutrient management practices are implemented is that nitrogen can be stored in aquifers for very long periods, possibly up to 50 years in the Bay region. (NRC 2011) However, Lindsay et al. (2003) have found that these "lag times" generally increase with stream order.[1] Thus monitoring of lower-order streams, as we propose, may help detect lessening of nitrogen impacts in local waters well before they appear in the larger water bodies.

BMP Treatment Efficiencies

Historically, the Chesapeake Bay Program has employed overly optimistic efficiency estimates for agricultural BMPs (and for BMPs for other land-based pollution sources) (Simpson and Weammert 2009), which likely gave more credit in the Bay model for pollution reductions than was merited. In response, an effort was undertaken to produce more realistic efficiency ratings. (NRC 2011; Simpson and Weammert 2009) These analyses of available study results and characterizations of practices on a watershed-wide scale are laudable and provide a strong foundation for further efforts.

The collection of expert reviews, subtitled "BMP Assessment: Final Report," was compiled under the leadership of Simpson and Weammert and the results are relatively well-suited to the large-scale accounting for land-based pollution control practices used by the CBP to judge overall progress in the Bay program. The authors and collaborators, in an attempt to allow for a range of factors that vary widely from one application to another, "including maintenance and longevity effects" of BMPs, assigned efficiency estimates based on averages from amongst the available data (with adjustments, based on professional judgments of analysts and commenters).

[1] A first order stream is one in the uppermost headwaters and has no branches. The confluence of two first order streams forms a second order stream; the confluence of two second order streams forms a third order stream; and so on. . . . When two streams of different orders meet, the higher order continues in the section downstream of their confluence. Usually, first through third order streams are considered headwaters. This system was first proposed by Strahler, A.N. (1952), *Hypsometric (Area Altitude) Analysis of Erosional Topology,* Geological Society of America Bulletin, *63 (11): 1117–1142.*

We believe the above-cited analytical approach constituted an important step in an ongoing process. We do not agree that an average of results, especially when those results vary so widely and with such an uneven distribution of values, can be fairly characterized as conservative in many cases.

But even if these results are judged to be acceptable, for the present, for use in the Bay model, watershed-wide averages are wholly inappropriate when making decisions about regulatory actions and trading credit assignments for specific cases. The ranges of efficiencies found from the disparate studies available in 2009 are sometimes very large so that crediting an activity with an average treatment value is inappropriate in many individual cases.

The inherent problems with applying a single effectiveness value to a BMP that is to be applied throughout the entire 64,000 square mile watershed that drains to the Bay are easily identified by examining the report's narrative. Some of the important points to note include:

- Pollutant reduction efficiencies are designed "[f]or use in calibration and operation of the Chesapeake Bay Program's 5.0 Watershed Model;" the stated objective of the report was "to develop definitions and effectiveness estimates that reflect the average operational condition representative of the entire watershed." (Simpson and Weammert 2009).

- Often, very limited numbers of studies that met the criteria for being included in the analyses were available to reviewers for developing averages.

- Within the groups of data used to develop the averages, there were often very wide ranges of efficiencies reported, including, in some case, practices with negative efficiencies, meaning that pollutant levels were higher after the measures were implemented than before.

- In some cases, measures that lessen overland runoff of pollutants allow greater amounts of pollutants to enter groundwater, which also contributes to surface water degradation but on a different time scale and through less easily-identified pathways.

- Often, measures that prevent sediment runoff are assumed to reduce phosphorous pollution to a comparable extent, because phosphorous is often bound to soil particles. However, this assumption does not hold when significant soluble phosphorous exists in the environment. For example: soil pH values in the mid-range will result in a larger amount of soluble phosphorus; coarse grained soils are more likely to allow leaching of phosphorus to water bodies; and animal manure used as fertilizer can yield greater phosphorus loss than will commercial fertilizers.

- The use of conservation tillage is often accompanied by increased use of chemicals and these contributions are not accounted for in assessing the overall value of the practices for the health of the Bay and local waters.

- While the Bay-wide averages assume a reasonable level of compliance with installation

> guidelines and practice definitions, as well as maintenance, the actual verification of these factors is extremely deficient. (Maryland makes field verification visits to about 7-8 percent of agricultural BMPs each year; NRC, 20011). As more BMPs are used, even this percentage will be difficult to maintain.

A broad concern about using the average values for the Bay model and overall views of improvement results is that the characteristics that make a practice more or less effective in one place versus another (e.g. soil types, geology, weather patterns) are not evenly distributed across the huge Bay watershed. More importantly, the overriding problem with applying Bay-wide average efficiencies to individual projects is that those averages often represent unacceptably wide variability for such applications. If, for example, the conditions that produced negative pollution removal results, actually increasing pollutant inputs to surface waters, exist at a particular site and the practice is used there anyway, then the assignment of credits is totally inappropriate and harmful to the overall effort.

Intensive Sampling During Storm Events

Scientists in many areas of the U.S. have recognized the need to sample throughout storm and runoff events as well as during base-flow conditions to assess the impacts of land-based pollution sources. The authors of one paper offered the following explanation for conducting storm event sampling:

> Most of the watershed–scale monitoring . . . involves continuous long–term monitoring, which is a valuable source of information and data for understanding the seasonal and yearly patterns of flow, sediment, and nutrients generated within agricultural watersheds. Gentry et al. (1998) and David et al. (1997) showed that heavy rainfall caused brief episodes of high discharges of water, sediment, and agrochemicals that make up a significant fraction of the total annual discharges. (Borah et al. 2002)

Even within the period of one storm event, a great majority of pollutants may be carried off the land very soon after runoff begins. (McDiffit et al. 1989)

Examples of research studies employing intensive storm sampling in agricultural environments, though not extremely numerous, are found for a variety of watershed types and sizes. We will not describe the varying studies reviewed in preparing this proposal in detail but refer readers to the following:

Bhat et al. (2007); Borah et al. (2002) (including brief descriptions of a number of prominent storm sampling studies); Borah et al. (2003); Ellis et al. (2011); Fisher et al. (2010); Harmel and King (2005); Houser et al. (2006); McDiffett et al. (1989); Robertson and Roeish (1999).

Other Pollutants of Concern in Agricultural Areas

In considering the importance of sampling for chemicals other than nutrients and sediments in the Bay watershed we refer readers to several important studies, as cited below, and provide some pertinent quotations. We note that, if we ignore these other contaminants while implementing corrective actions for the priorities currently in vogue, then we may worsen some pollution problems while solving others. Further, if BMPs could address the entire suite of contaminants in this first round of implementation, such an approach could avoid the need for additional actions and/or retrofits later and at greater expense.

USGS researchers Hamilton and Shedlock (1992) authored *Are Fertilizers and Pesticides in the Groundwater? - A Case Study of the Delmarva Peninsula, Delaware, Maryland, and Virginia.* Important points from their analysis include:

- "In the Delmarva Peninsula, nearly 3 million pounds of these chemicals are used annually for agricultural purposes. Most by far are herbicides, with metolachlor (such as Dual), alachlor (such as Lasso), and atrazine (such as AAtrex) accounting for about 70 percent. These herbicides are used primarily on corn and soybeans, the two most widespread crops in the Delmarva Peninsula."

- Two of the most commonly used herbicides, alachor and atrazine, were detected in a significant number of well samples.

- "In most water samples in which herbicides were detected, the well was near farmland (generally within 100 feet)." The presence of calcium, magnesium, and nitrate as major constituents in these well samples indicates that the water was affected by agricultural lime and fertilizers.

Hancock et al. (2005) did reconnaissance sampling to look at arsenic in poultry manure, groundwater, surface water, agricultural ditch water, agricultural soil, forest soil, bed sediment, and cored sediments of the Pocomoke River Basin. They observed that:

- "Shallow ground water from piezometers near agricultural fields, which had total dissolved arsenic concentrations as high as 23 µg/L, appears to be an important reservoir for arsenic cycling in the Pocomoke Basin."

- "Base-flow concentrations of total dissolved arsenic were within the ranges found in other tributaries of the Delmarva Peninsula that are dominated by agriculture, but have a lower density of poultry operations. Concentrations of total dissolved arsenic in agricultural ditches and in the main stem of the Pocomoke River increased during high flow, presumably due to runoff."

Finally, a recent U.S. EPA report, *Literature Review of Contaminants in Livestock and Poultry Manure and Implications for Water Quality* (2013), provides a comprehensive view of these issues.

Adkins Race Subwatershed

To choose sampling sites that might meet our goals for this project, we assessed a number of sub-watersheds across the eastern shore of Maryland looking for areas with the following characteristics:

A. Large percentages of watershed area in farming.

B. Streams with acknowledged water quality problems attributable largely to agricultural inputs.

C. Streams with useable water quality data that can be supplemented by additional monitoring efforts.

D. Areas where significant effort has been made and/or is planned to implement BMPs.

E. Sampling sites that can be easily accessed and monitored.

Based on the information available, the Adkins Race watershed seems to meet all of the above criteria. Adkins Race is a 3rd-order stream and a tributary to the upper portion of the Pocomoke River. It flows into the River from the east and its watershed is entirely within Wicomico County. Within a short distance upstream from its mouth, the watershed all feeds Adkins Pond and the drainage area at this point is 21.6 square miles. (MDE 2002) Several main tributaries provide nearly all of the flow to the Pond: Truitt Branch, Savanna Branch and Campbell Ditch merge just above the Pond to form one tributary, and Givens Branch is the other major contributor. Given the abundant wetlands in the area and the predominant geologic and hydrologic features on the Eastern Shore, groundwater flow is also virtually certain to contribute to the Pond to a large extent, especially in dry weather periods.

Map 1. Location of Adkins Race watershed on Eastern Shore

Map 2. Location of Adkins Race Watershed in Wicomico County, Maryland

As reported by the Maryland Department of the Environment,

> Adkins Pond is impacted by a high sediment load, which has resulted in excessive sedimentation and loss of the pond's volume. This threatens the ability of the water body to maintain and support fishing, and propagation of fish and other aquatic life. The pond also experiences occasional nuisance seasonal algae blooms, due to over enrichment by nutrients, which interfere with recreational uses. The death and decay of excessive algae can cause violations of the water quality standard for dissolved oxygen (DO), which can result in a disruption of the pond's ecosystem balance and cause fish kills. (MDE 2002)

The State of Maryland designated Adkins Pond as "impaired" for nutrients and sediments and EPA has approved a TMDL prepared by the State. At the time the TMDL was approved in 2002, the Pond suffered from nuisance algae blooms and low dissolved oxygen (DO) levels, and was estimated to have lost about 61% of its volume to sediment deposits. The Pond was first placed on Maryland's 303(d) list in 1998 and it remained on the list in 2012. The State identified agriculture as the source of impairments for phosphorus and sediments. (MDE 2002)

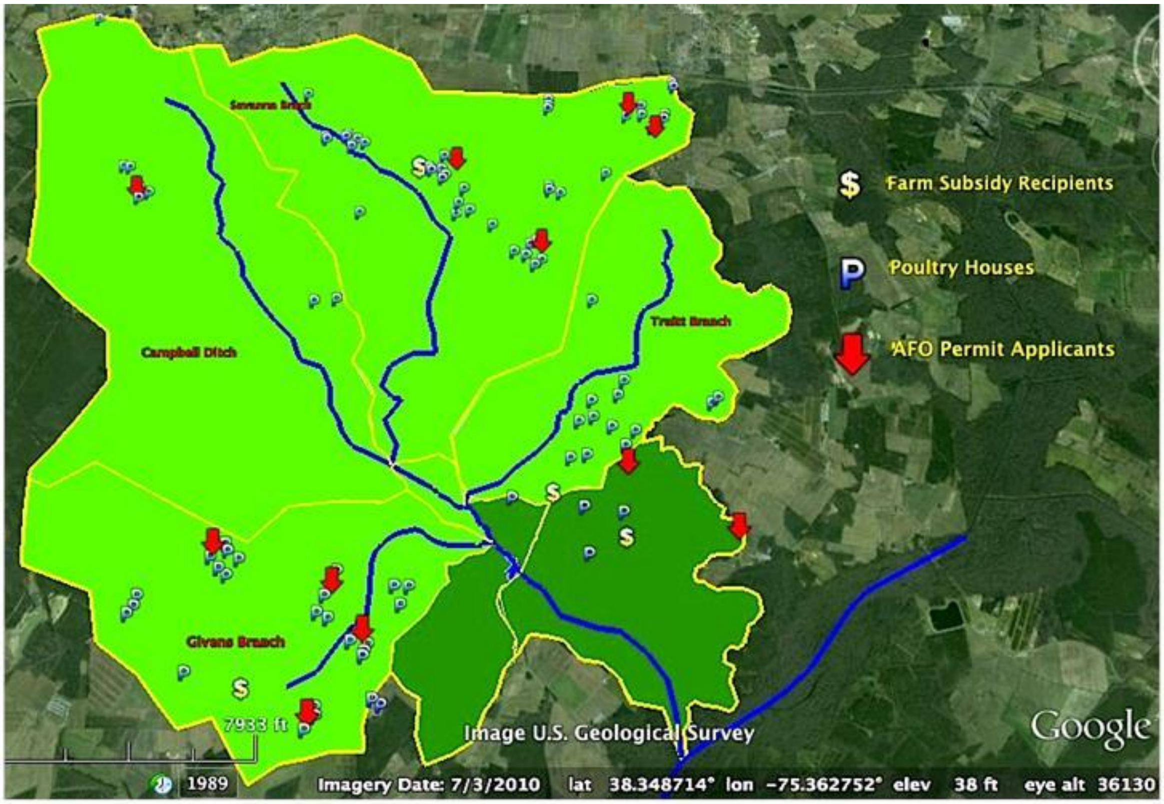
The watershed draining to Adkins Pond is estimated to have 54% of its land area in farming and 46% in forests. This is in contrast to the Pocomoke River watershed as a whole, which has only about 25% agricultural area. For our purposes, this mix of land uses is particularly useful to isolate the effects of farming on water quality. While intact forests certainly contribute nutrients to nearby water bodies, the levels of input are much smaller than those from other land uses.

An examination of Google Earth photos reveals well over 100 poultry houses in the Adkins watershed along with significant areas in crops. This accounting is supplemented by information published by Chesapeake Commons (2013) showing the locations of farms in the watershed that have applied to the State for permit coverage as Confined Animal Feeding Operation (CAFOs) and Maryland Animal Feeding Operations (MAFOs). Finally, the Environmental Working Group maintains web records of farmers who have received federal subsidies and we located those in the area of Adkins Run who had received "conservation subsidies" between 1995 and 2012. (EWG, 2013) (See Map 3 for locations of these features)

A large amount of water quality data has been reported for Adkins Pond, through the TMDL process and through other assessments of the watershed streams. Adkins Race was recommended to be amongst the highest priority sites for protection and restoration in a 2002 report by the Maryland Department of Natural Resources (DNR).

The Maryland State Highway Administration owns Adkins Pond and the Pond is surrounded by a public park operated by Wicomico County. The Park has walking trails and a boardwalk which should provide access to the tributaries for sampling and areas of the Pond can be accessed by boat. In addition, there are sites along the tributaries that should provide access for sampling from public roads. The tributary streams are small and shallow during base flow conditions and should also be safe and easily accessible during storms.

Map 3. Farm Locations (light green shading covers drainage area that would be covered by proposed monitoring stations).



Proposed Monitoring Plan

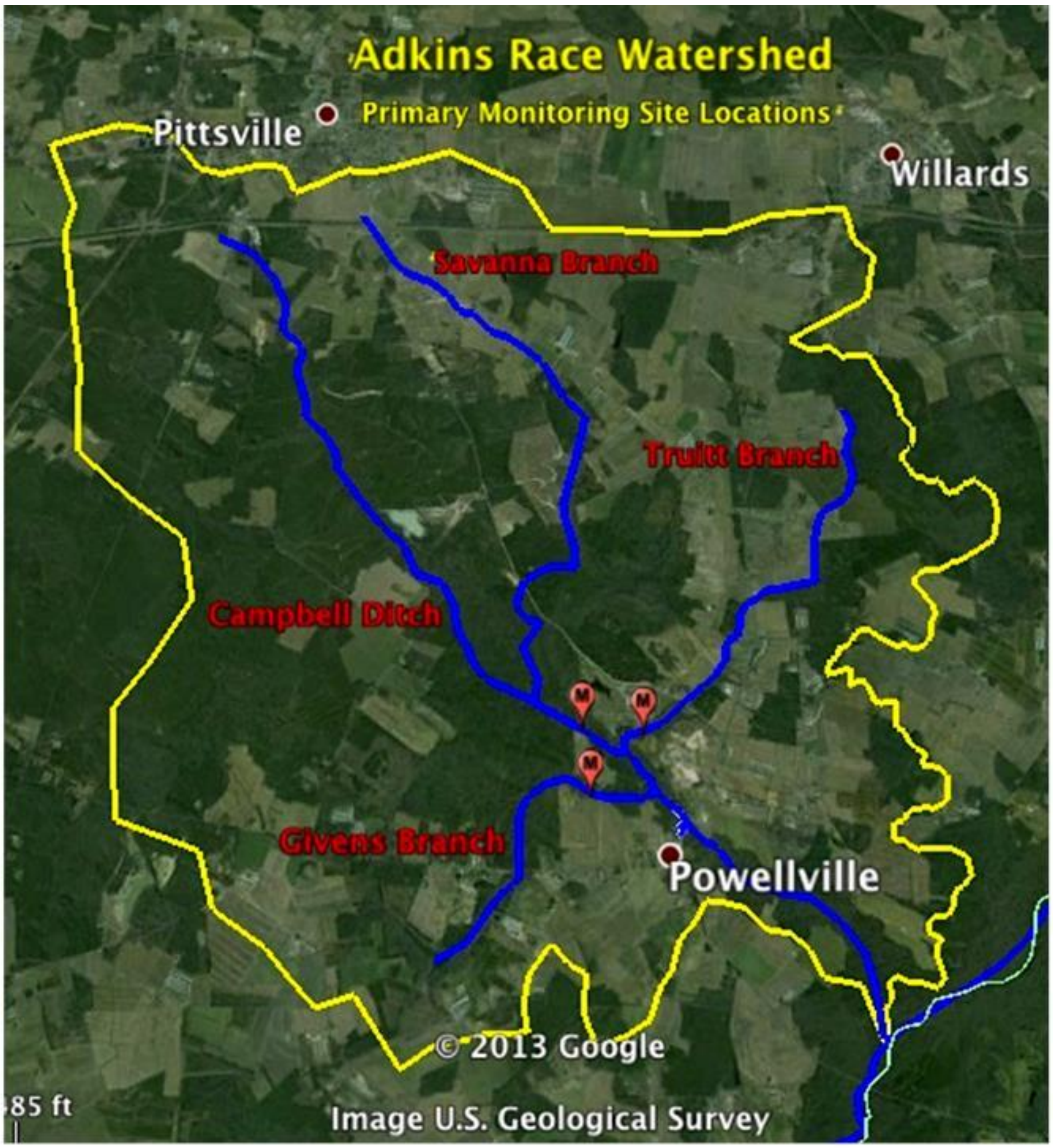
As explained above, sampling throughout storm events, combined with samples collected on a more random schedule, will reveal information about the Adkins Race watershed that cannot be gained otherwise. This suggested protocol is similar to and informed by the references listed above. Before sampling begins, a thorough written plan, including quality assurance/quality control procedures would be prepared. The proposed monitoring program would include the following features:

Locations

There are a number of possible sites at which monitoring can be conducted in the watershed above Adkins Pond. Based on information examined so far, without having completed a field assessment, it appears that from one to three sites just upstream of the impounded section of Adkins Race (known as Adkins Pond) will be a suitable area to assess pollution amounts coming from the agricultural operations in an area about 26 square miles.

One station placed just upstream of the impounded area of the Pond, in a section that flows freely, could characterize inputs from the entire watershed. Given that there are several primary tributaries to the Pond and that those smaller drainages have significantly different features, moving upstream and monitoring above the confluences of these three streams would be preferable, if sufficient resources allow. Map 4 shows potential sites. In addition to these intensively-monitored sites, there are many road crossings from which one could collect grab samples.

Map 4. Primary Monitoring Site Locations



Parameters

Below is a list of parameters that we would propose to monitor at some or all of the sites identified above.

- Nutrients
  - Phosphorous - Total
  - Nitrogen - Total
- Sediments - Total Suspended Solids and turbidity
- Heavy Metals - A standard suite of metals to include arsenic, lead, cadmium, chromium, copper, etc.
- Pesticides - Particularly Atrazine, Alochlor, and their degradation products.
- Drugs - A range of hormones and antibiotics to be determined, based on existing data
- Temperature - field measurements
- Dissolved Oxygen - field measurements
- pH
- Turbidity
- E.coli bacteria
- Photographs
- Stream flow measurements - both automated and manual to calibrate
- Rainfall amounts and timing - data from Salisbury airport likely adequate

We would also want to collect information about the routing of drainage ditches and relations to sub-watershed boundaries, and observations and documentation of agricultural operations, BMPs or other activities that may affect water quality. The latter, in particular, is critical to showing any correlations between water quality data and BMP implementation.

Timing

Historically, some of the highest monthly average rainfall amounts in this area occur in March. We recommend sampling of both storm events and base flows starting in this period or just before. By pairing stream flow monitoring over time with rainfall data we will be able to distinguish between the times when streams are affected by storms and increased runoff and those when groundwater comprises the main source of surface flows. Hydrographs showing variations in stream flow over time, paired with rainfall data, will provide information about the duration and intensity of storm impacts on stream flows.

Storm event composite sampling should begin in March and a succession of at least three significant rain events should be covered by this sampling over the next several months, depending on study and resource constraints. Extension of sampling into June or July is more likely to catch intense summer storm events, which would be preferable.

Grab samples from various locations should be sampled to strategically supplement the locations where intensive sampling occurs (e.g. in extreme headwaters to characterize “background” conditions, between individual farms to compare impacts, etc.).

Equipment

Grab samples can be collected by hand in the proper containers for transport to the lab and stored in iced coolers. While storm samples could also be collected by hand, a much more practical method is to use automated devices. We recommend the use of ISCO automatic samplers to collect composite samples. These may be set to be activated by initial rises in stream levels, or can be started manually at some period before an expected storm begins. The samplers can collect discrete samples that are spaced by time increments or they can be flow-weighted. It would be important and necessary to place the automatic samplers carefully and secure them to avoid vandalism and theft. The samplers can be packed with ice to chill samples to the proper temperature until they can be collected.

Several companies rent these kinds samplers for reasonable prices (est. $350.00 per month). Based on the number of months they are to be deployed and the number used and the likelihood that there would be future uses for the machines, we can compare the merits of renting versus buying samplers.

Sampling containers could be obtained from the lab that is to conduct analysis or from a separate supplier, based on price and convenience/timing. We would recommend that any preservatives to be used in sampling be obtained from the lab and, where possible, that they be placed in the bottles before entering the field. We make this suggestion to avoid dangers from the storage and use of significant amounts of acids (e.g. nitric acid used to preserve metals samples) or other hazardous chemicals.

Another key component of the equipment will be a method to measure flow volumes over long periods to characterize conditions under both baseflow and storm conditions. These measurements can be paired with sample concentrations to calculate pollutant loadings. There are now sensors that can be placed in surface waters and can measure the depth of the stream, through sensing pressure differences bearing on the instrument. To prepare for the use of these instruments, one would need to take manual measurements, probably using a “pygmy” meter, so that a scale can be constructed to convert stream depths to stream flow values.

It would probably be necessary to have a canoe and either a pickup truck or a large vehicle when the samplers are to be placed and/or removed. After the samplers are in place, we believe they are likely reachable by foot, based on the information we have at this time.

People

One person could conduct much or all of the monitoring activities, though it is preferable to have two or more people with a working knowledge of the methods being used and the locations that must be accessed. The placement and retrieval of automatic samplers and other equipment would be more efficient and safer with at least two workers. The leader of the effort needs to have considerable knowledge of the principles of sampling and flow measurement, as judgments will need to be made in the field that could have serious consequences for the success of the project overall. Others participating need not have significant prior experience and can be trained during the project.

Broader Application of the Monitoring Protocol

The monitoring system proposed for Adkins Race watershed is intended to characterize the movement of pollutants off of farm lands in this particular drainage but should provide insights into the ways similar watershed work. We believe the results will be suitable for making predictions about agricultural pollutant loads in at least a significant portion of the Delmarva Peninsula, where similar environments and farming activities exist.

In replicating the work on the eastern shore, one method for picking the numbers and areas to be covered by representative sampling would be based upon Physiographic Provinces and possibly their subdivisions. Six such provinces are identified in Maryland, as shown below, and our focus on the Chesapeake Bay drainage allows us to eliminate the Atlantic Coast Province from consideration in this report.

Some of these Provinces are sub-divided into Sections and then Regions, based on their structural characteristics. We would suggest that the monitoring protocol described here should be reproduced in, at least, the four other physiological Provinces within Maryland.

In addition to these underlying natural conditions in each Province, the nature of farming operations may vary considerably from one part of a Province to another. For example, an area that is predominantly used for pasture or dairy cattle versus one with crops will likely have very different runoff characteristics.

The Provinces are (Reger and Cleaves 2008):

- I. Appalachian Plateaus Province
    - Alleghany Mountain Section
- II. Ridge and Valley Province
    - Folded Appalachian Mountains Section
    - Great Valley Section
- III. Blue Ridge Province
- IV. Piedmont Plateau Province
    - Lowland Section
    - Upland Section
- V. Coastal Plain Province
    - Embayed Section
        - Western Shore Uplands Region
        - Western Shore Lowlands Region
        - Chesapeake Estuary Region
        - Delmarva Peninsula Region
- VI. Atlantic Continental Shelf Province

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