Unsustainable Agriculture

Pennsylvania's Manure Hot Spots and their Impact on Local Water Quality and the Chesapeake Bay

ENVIRONMENTAL INTEGRITY PROJECT

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THE ENVIRONMENTAL INTEGRITY PROJECT

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PHOTO CREDITS

Cover photo of a manure spreader from Ohio State University College of Food, Agricultural and Environmental Sciences. Photo of hogs from National Institutes of Health.

Unsustainable Agriculture: Pennsylvania's Manure Hot Spots

Executive Summary

Pennsylvania's agriculture sector has a big pollution problem. As part of the Chesapeake Bay watershed, Pennsylvania is one of the states responsible for decreasing the nitrogen, phosphorus and sediment pollution loads that degrade the Bay. Most of Pennsylvania's contribution to these loads comes from agriculture.

- Pennsylvania is responsible for roughly half of the nitrogen entering the Chesapeake Bay each year, and more than a quarter of the phosphorus. The agricultural sector in Pennsylvania alone is responsible for 26 percent of the nitrogen and 16 percent of the phosphorus entering the Chesapeake Bay each year.

The Bay states are working with the EPA to implement a "pollution diet" for the Bay, known as the Total Maximum Daily Load or Bay TMDL. Pennsylvania's agriculture sector is struggling to keep up with the progress that other Bay states are making.

- While the other Bay states are within one million pounds of their 2017 agricultural nitrogen pollution reduction targets, Pennsylvania is off by 16 million pounds (or 36 percent).

- Pennsylvania is the only Bay state that has not met its 2017 target for agricultural phosphorus.

Part of the problem is that Pennsylvania's agriculture industry has become larger, more concentrated, and more intensive over time. EIP looked closely at four counties where the per-acre application of nitrogen and phosphorus is the highest – Franklin, Lancaster, Lebanon, and Union Counties. This report examines input data and model estimates from the Chesapeake Bay Program's revised Bay Model, and compared these four counties to the rest of the Commonwealth.

Hog production – and hog manure production – has nearly doubled since the 1980s in Pennsylvania's Lancaster, Lebanon, Franklin and Union counties.

The four counties have always produced more animals and applied more manure to cropland than other counties within Pennsylvania. In recent years, compared to other Pennsylvania counties in the Bay watershed, there are roughly twice as many turkeys per farm acre, three times as many dairy cows, and six times as many chickens. In other words, there is much more manure produced in the four focus counties relative to the amount of land suitable for manure application.

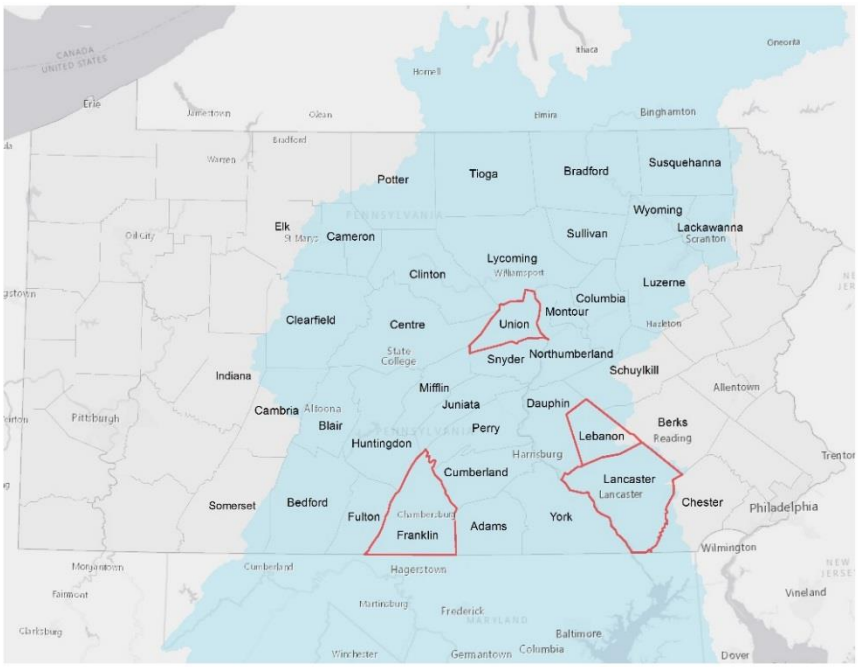
Many of these animals are confined in large, federally-defined C oncentrated Animal Feeding Operations (CAFOs). The majority of CAFO animal production in Pennsylvania's part of the Bay watershed happens in these four counties. Since the mid 1980s, hog production in these counties (at CAFOs and elsewhere) has nearly doubled, turkey production has increased by 70 percent, and broiler production by 44 percent. Along with the increasing density of animal production comes more manure. Although not all manure stays on the farm where it is generated, most stays within county lines. As a result, these four counties have been adding more and more manure to each available acre over time.

- Since 1984, the per-acre application of manure nitrogen has increased by 40 percent in the four counties that we analyzed. Applications in the rest of the Commonwealth have also increased, but only by 9 percent.

- The per-acre application of manure phosphorus has increased by 27 percent since 1984, twice as fast as the rest of the Commonwealth.

- In other parts of Pennsylvania, the majority of nitrogen and phosphorus applied to cropland comes from chemical fertilizer. In the four counties we analyzed, 61 percent of the nitrogen and 76 percent of the phosphorus comes from manure.

- The four counties we analyzed apply 4-5 times more manure nitrogen and manure phosphorus than the rest of the state, per acre of farmland.



Pennsylvania's Lancaster, Lebanon, Franklin and Union Counties are manure hot spots. The Chesapeake Bay watershed is highlighted in blue.

Along with all of this manure comes ammonia, which is emitted from livestock and poultry confinements, manure storage, and land-applied manure and then re-deposited on local land and water. Compared to the rest of the Commonwealth, there is twice as much ammonia deposition in the four counties that we analyzed, adding an extra dose of nitrogen.

Manure is routinely over-applied to cropland, adding more nitrogen and phosphorus than crops can use. In the best cases, manure is applied to maximize crop yield, but without adequate efforts to reduce runoff. In the worst cases, manure applications are simply waste disposal. In the four focus counties, over-applications of nitrogen and phosphorus in 2013 – meaning the amount applied in excess of crop uptake – was 34 pounds per acre (nitrogen) and 18 pounds per acre (phosphorus). Outside of the four focus counties, over-applications were much less, at 14 pounds per acre (nitrogen) and 0.03 pounds per acre (phosphorus).

- Although Pennsylvania formally regulates manure applications, the rules have traditionally been treated as effectively voluntary. As of January 2016, state officials estimated that only 30 percent of farms had manure management or erosion control plans. The situation may be improving, with a survey released by the state in August 2017 finding that about 60 percent of farms had these plans. There is still much room for improvement however, and the recent inspections did not evaluate compliance with manure management plans.

Enforcement of these regulations is rare, and undermined by severe budget cuts at the Pennsylvania Department of Environmental Protection, which has seen its funding slashed by about 40 percent over the last 15 years.

More importantly, the regulations that apply to most farms are extremely lax. Even if farmers were fully compliant with the existing rules, manure would still be over-applied.

As a result, water quality has suffered. In the rest of the Commonwealth, roughly 8 percent of stream miles are impaired by agriculture. Within the four counties, 24 percent of stream miles are impaired by agriculture, with too much nitrogen, phosphorus, bacteria, and/or siltation. Another 29 percent of streams have unsafe levels of bacteria from unknown sources; these unknown sources are likely to include agriculture. In-stream monitoring of nitrogen and phosphorus shows unhealthy levels of both in the water that drains from Franklin and Lancaster Counties. In Lancaster County alone, 40 percent of stream miles are impaired by agricultural runoff pollution, including 106 miles impaired by pathogens and 462 miles by nitrogen and phosphorus. In recent years, phosphorus levels in Lancaster County have been both unhealthy and rising.

The intensity of animal production and land-application of manure in the four counties is unsustainable. These counties generate more manure than available cropland can safely absorb, and animal production exceeds the carrying capacity of the landscape. In order to better protect both local water quality and the Chesapeake Bay, there are several steps that Pennsylvania should take:

- Reduce animal production to a more sustainable level.

- In the meantime, it will be critical for the Commonwealth to maximize the efficient application of manure. Voluntary programs, which incentivize the use of certain Best Management Practices, are not working. Pennsylvania should require all farms that land-apply manure, particularly farms in areas that have intensive animal production, to have and follow Nutrient Management Plans.

- Require universal implementation of Pennsylvania's Phosphorus Index, a field evaluation tool developed to identify areas that are likely to discharge phosphorus to surface water.

- Eliminate its ban on stream fencing regulations and require practices that keep livestock out of streams

- Prohibit or restrict winter spreading of manure, as other Bay states have done.

- Require, statewide or in agricultural hotspots, the implementation of advanced nutrient management practices such as immediate manure incorporation, split applications, and the regular use of manure tests and soil tests.

Undertaking these steps would reduce the loss of nitrogen and phosphorus to the environment while maintaining optimal crop yields. Failure to take these concrete steps will mean that local water quality will continue to suffer, and Pennsylvania will continue to fall behind Chesapeake Bay cleanup targets.

Table of Contents

1. Introduction

The Chesapeake Bay states are making notable progress in cleaning up the Bay. Since 2010, the states, the U.S. EPA, and other partners in the Chesapeake Bay Program Partnership have been working to implement a "pollution diet" for the Bay, known as the Total Maximum Daily Load, or TMDL. Two of the key pollutants that the TMDL seeks to reduce are nitrogen and phosphorus, sometimes referred to as "nutrients," which stimulate algae blooms and, as algae die and decompose, create low-oxygen dead zones. Between 2009 and 2015, simulated nitrogen and phosphorus loads to the Chesapeake Bay declined by 8 percent and 20 percent, respectively.[1] The industrial and municipal wastewater sectors, in particular, have made significant reductions and are currently meeting future TMDL targets.[2]

Yet despite some signs of improvement, the Bay remains significantly impaired. According to the U.S. EPA, "[t]he Bay's health has slowly improved in some areas. However, the ecosystem remains in poor condition. The Bay continues to have polluted water, degraded habitats, and low populations of many fish and shellfish species."[3] There is still much work to be done. Continued progress will depend on additional reductions from certain key areas. One of these is Pennsylvania's agriculture sector. It will be very difficult for the Chesapeake Bay to meet 2017 and 2025 cleanup targets unless Pennsylvania can reduce its agricultural pollution. A few statistics should make this clear:[4]

- In 2016, nearly half (47 percent) of the Bay's nitrogen load came from Pennsylvania, as did 28 percent of the phosphorus and 31 percent of the sediment.
- Most of Pennsylvania's pollution comes from the agriculture sector. Agriculture accounted for 56 percent, 59 percent, and 62 percent of the Commonwealth's nitrogen, phosphorus, and sediment loads in 2016.
- In other words, Pennsylvania agriculture is responsible for 26 percent of the nitrogen reaching the Bay each year, 16 percent of the phosphorus, and 19 percent of the sediment.
- Pennsylvania is also struggling more than the other Bay states to meet cleanup targets. **Tables 1 through 3** show that Pennsylvania's agriculture sector is further behind 2017 and 2025 targets than the agriculture sectors of the other states. For example, while the other states are all within one million pounds of their 2017 agricultural target for nitrogen, Pennsylvania exceeds its target by more than 16 million pounds. And while the rest of the Bay states are ahead of their 2017agricultural targets for phosphorus, Pennsylvania is still behind.

- Between now and 2025, Pennsylvania will have to reduce nitrogen, phosphorus, and sediment loads from agriculture by 77 percent, 38 percent, and 38 percent, respectively, to meet its obligations under the Bay TMDL.

The excess nitrogen and phosphorus is not just a problem for the Chesapeake Bay; it also creates significant local water quality problems. This is particularly true in Lancaster County, where both nitrogen and phosphorus exceed healthy levels, phosphorus has been increasing in recent years, and at least 40 percent of streams are formally "impaired" by agriculture (see Section 4 of this report for more details on local water quality problems).

Table 1. Difference between 2016 Agricultural Loads and 2017 Agricultural Targets (lbs/year). [5]

State	Nitrogen	Phosphorus	Sediment
NY	750,098	(6,919)	14,949,525
PA	**16,592,334**	**325,601**	**178,322,023**
MD	912,291	(117,447)	(191,287,893)
VA	929,945	(388,427)	255,500,279
WV	(45,016)	(35,716)	(9,172,221)
DE	209,318	(33,759)	(16,727,176)

Note: Positive values show excess loads, or the amount by which 2016 loads exceeded 2017 targets. Negative values (in parentheses) show the amounts by which simulated loads in 2016 were lower than 2017 targets.

Table 2. 2016 Agricultural Loads/2017 Agricultural Targets (%). [6]

State	Nitrogen	Phosphorus	Sediment
NY	121%	98%	113%
PA	**136%**	**115%**	**113%**
MD	105%	92%	75%
VA	106%	90%	113%
WV	98%	92%	96%
DE	107%	87%	74%

Note: Values less than 100% indicate that the 2016 load was lower than the 2017 target.

Table 3. 2016 Agricultural Loads/2025 Agricultural Targets (%).[7]

State	Nitrogen	Phosphorus	Sediment
NY	144%	116%	128%
PA	**177%**	**138%**	**138%**
MD	118%	97%	74%
VA	129%	109%	136%
WV	105%	106%	115%
DE	127%	98%	74%

Note: Values less than 100% indicate that the 2016 load was lower than the 2017 target.

The primary purpose of this report is to examine the causes of Pennsylvania's agricultural pollution problem and to offer possible solutions. Two critical, interrelated causes appear to be high-density animal production and weak state rules regarding the land-application of manure. Most counties in Pennsylvania have been packing more and more animals onto their farmland, and the four counties we are focusing on in this report are generally no different. This means that the amount of manure has also been increasing. Most of the manure generated in a county stays within that county, even if some is transferred from one farm to another. As a result, counties with high animal density also have high per-acre manure applications. Unless farmers in counties with intensive animal production are exceptionally careful about how much manure their crops actually need and how much they apply, much of the nutrient content in the manure will continue to be lost, with consequences for both the Chesapeake Bay and local water quality.

2. Agricultural hot spots

a. Nutrient application rates

I. CURRENT APPLICATION RATES

According to the Chesapeake Bay Program's watershed model,[8] nitrogen and phosphorus are applied to land in Pennsylvania[9] at rates of roughly 50 pounds per acre per year for nitrogen and 10 pounds per acre per year for phosphorus. However, more than 95 percent of these nutrients are applied to agricultural land, and agricultural applications are more intensive. The Chesapeake Bay Program estimates that nitrogen and phosphorus were applied to Pennsylvania's agricultural land at average rates of 69 and 15 pounds per acre, respectively, in 2013.[10]

These statewide averages hide significant variation among counties. **Table 4** shows the 20 counties in the Chesapeake Bay watershed with the highest agricultural nitrogen application rates. Nine of these counties are in Pennsylvania. **Table 5** shows the 20 highest phosphorus-applying counties. Lancaster and Lebanon Counties stand out as having nutrient application rates higher than almost anywhere else in the Chesapeake Bay watershed.

Table 4. 2013 Nitrogen Application Rate on Agricultural Land: Twenty Highest Counties in the Chesapeake Bay Watershed[11]

State	County	Nitrogen Application Rate (lb/acre)
MD	Somerset	177
PA	Lancaster	147
DE	Sussex	135
PA	Lebanon	124
VA	Rockingham	108
MD	Worcester	106
VA	Page	103
MD	Caroline	100
MD	Wicomico	97
DE	Kent	97
PA	Franklin	92
VA	Accomacl	89
DE	New Castle	87
WV	Hardy	87
PA	Berks	86
PA	Blair	85
PA	Cumberland	85
PA	York	83
PA	Union	81
PA	Chester	78

Table 5. 2013 Phosphorus Application Rate on Agricultural Land: Twenty Highest Counties in the Chesapeake Bay Watershed[12]

State	County	Phosphorus Application Rate (lb/acre)
MD	Somerset	54.5
PA	Lancaster	40.3
PA	Lebanon	34.8
DE	Sussex	32.3
VA	Page	31.7
VA	Rockingham	30.9
MD	Wicomico	29.7
WV	Hardy	26.3
VA	Amelia	23.8
MD	Worcester	23.8
PA	Union	21.9
MD	Caroline	21.7
PA	Snyder	20.9
PA	Dauphin	20.9
VA	Accomack	20.7
PA	Franklin	20.2
VA	Cumberland	19.6
DE	Kent	19.5
PA	Berks	19.0
PA	Schuylkill	18.2

The remainder of the report will focus on the four Pennsylvania counties that appear among the top twenty lists shown above for both nitrogen and phosphorus application (with the exception of Berks County, most of which is located outside the Chesapeake Bay watershed). The four Pennsylvania counties within the "top 20" are Lancaster, Lebanon, Franklin, and Union. This list includes the three highest nitrogen-applying counties in Pennsylvania, and also the three highest phosphorus-applying counties. These four counties are compared, individually and as a group, to the other Pennsylvania counties in the Chesapeake Bay Watershed in Appendix A. **Table 6** summarizes this comparison for the four counties as a group.

To begin, **Table 6** provides a snapshot of the most recent nitrogen and phosphorus application rate estimates from the Chesapeake Bay Program. The four focus counties add 2-3 times more nitrogen and phosphorus to agricultural land than the other counties in the Commonwealth.

Table 6. Comparing the four counties (Franklin, Lancaster, Lebanon, and Union) to other Pennsylvania Counties in the Chesapeake Bay Watershed

	Four Focus Counties	Other Counties
Nitrogen		
Pounds per agricultural acre, 2013[13]	121	59
Change in the rate of application, 1984-2013[14]	+24%	+9%
Manure as source of cropland applications (%)[15]	61%	28%
Manure nitrogen per agricultural acre, 2013[16]	74	17
Change in manure applications, 1984-2013[17]	+40%	+9%
Ammonia nitrogen deposition, 2014 (lb/acre) [18]	7.1	3.1
Phosphorus		
Pounds per agricultural acre, 2013[19]	32	12
Change in the rate of application, 1984-2013[20]	+4%	-23%
Manure as source of cropland applications (%)[21]	76%	42%
Manure phosphorus per agricultural acre, 2013[22]	24	5
Change in manure applications, 1984-2013[23]	+27%	+13%
Concentrated Animal Production		
Livestock at CAFOs, % of PA total[24]	47%	53%
Poultry production at CAFOs, % of PA total[25]	63%	37%

II. TRENDS IN NITROGEN APPLICATION RATES

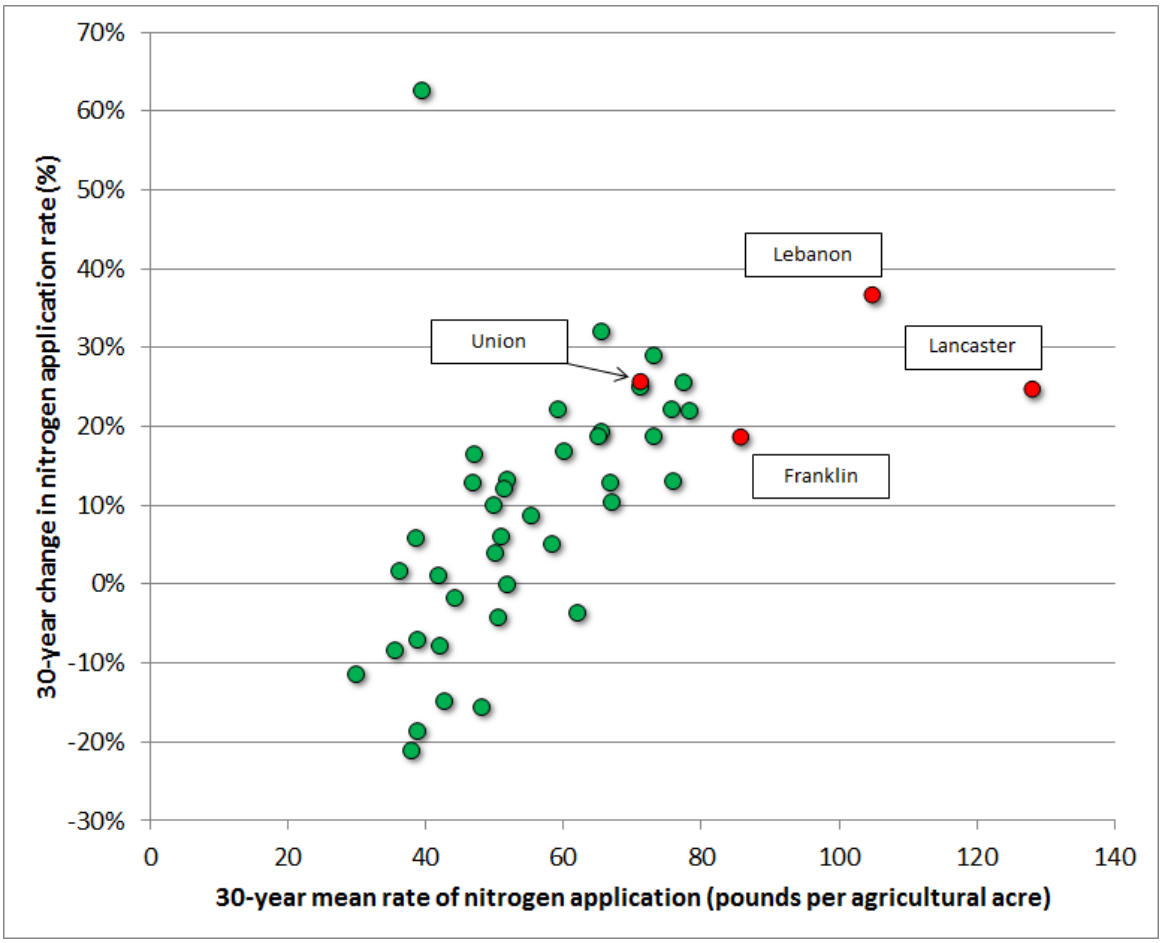
Since 1984, the nitrogen application rate in Pennsylvania has increased by about 13 percent. Again, there are significant differences among counties, but there is a notable correlation between trends and baseline nitrogen application rates. **Figure 1** shows the 30-year change in nitrogen application rates as a function of the 30-year average application rate, and shows a growing divergence between counties that are more or less intensive with their nitrogen applications. Counties with lower historical application rates have seen a decrease in nitrogen application intensity over time. On the other hand, counties with high application rates have seen a relatively steep increase in application intensity.

The four focus counties, like the rest of the Commonwealth, have lost about 10 percent of their farmland since 1984. But the four focus counties have been intensifying their application of nitrogen to the remaining acres at a rate far higher than the rest of Pennsylvania. Since 1984, the rate of nitrogen application in the focus counties has increased by 24 percent. In the rest of the Commonwealth, the rate of nitrogen application has increased by 9 percent. Over the past ten years the trend is the same – the intensity of

nitrogen applications has increased statewide, but it has increased much faster in the four focus counties.

In short, the most nitrogen-heavy areas of the Commonwealth are becoming even more nitrogen-heavy over time.

Figure 1. Changes in nitrogen application on Pennsylvania agricultural land as a function of long-term average application rates, by county, with the four focus counties in red.[26]



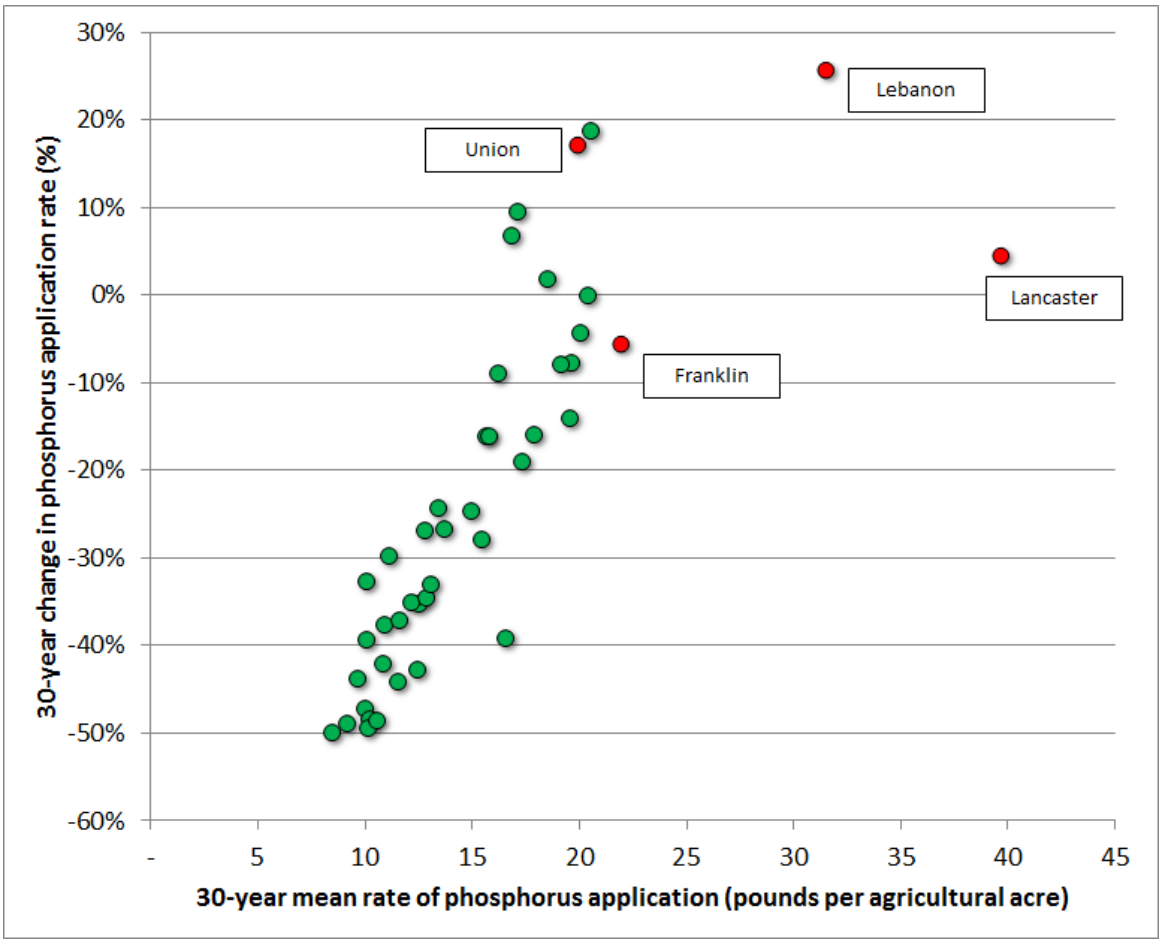
III. TRENDS IN PHOSPHORUS APPLICATION RATES

Unlike nitrogen, statewide phosphorus application has been declining. Since 1984, the rate of phosphorus application has dropped by about 15 percent. But as with nitrogen, long-term trends are correlated with historical application rates (see **Figure 2**). Compared to the rest of the Commonwealth, the counties with high historical application rates have been reducing the application rate more slowly; in several of these counties, including three of the four focus counties, the phosphorus application rate has been increasing.

Over the long term, where the rest of the Commonwealth has reduced phosphorus application rates by 23 percent, the four focus counties have increased their phosphorus

application rates. The phosphorus application rate in Lebanon County has increased by 26 percent. Over the short term (since 2004), three of the four focus counties have accelerated their phosphorus applications while the rest of the Commonwealth continues to decline. Again, as with nitrogen, some of the most phosphorus-heavy areas of Pennsylvania are becoming even more phosphorus-heavy over time.

Figure 2. Changes in phosphorus application on Pennsylvania agricultural land as a function of long-term average application rates, by county, with the four focus counties in red.[27]



b. Sources of nitrogen and phosphorus

The sources of nitrogen and phosphorus that farmers apply to cropland are manure, synthetic fertilizer, and biosolids (treated human waste). Outside of the four focus counties, most nitrogen and phosphorus is applied as fertilizer. Within the four counties, the opposite is true and most of the nitrogen and phosphorus is applied as manure. Specifically, manure accounts for 61 percent of nitrogen and 76 percent of phosphorus applications. **Figures 3 and 4** provide a comparisons of the manure-fertilizer balance over time. In the four focus counties, not only is manure the dominant source of land-applied nutrients, it is also a source that is increasing over time.

Figure 3. Nitrogen applied to cropland as manure and fertilizer in the four focus counties (left) and the rest of the Commonwealth (right)[28]

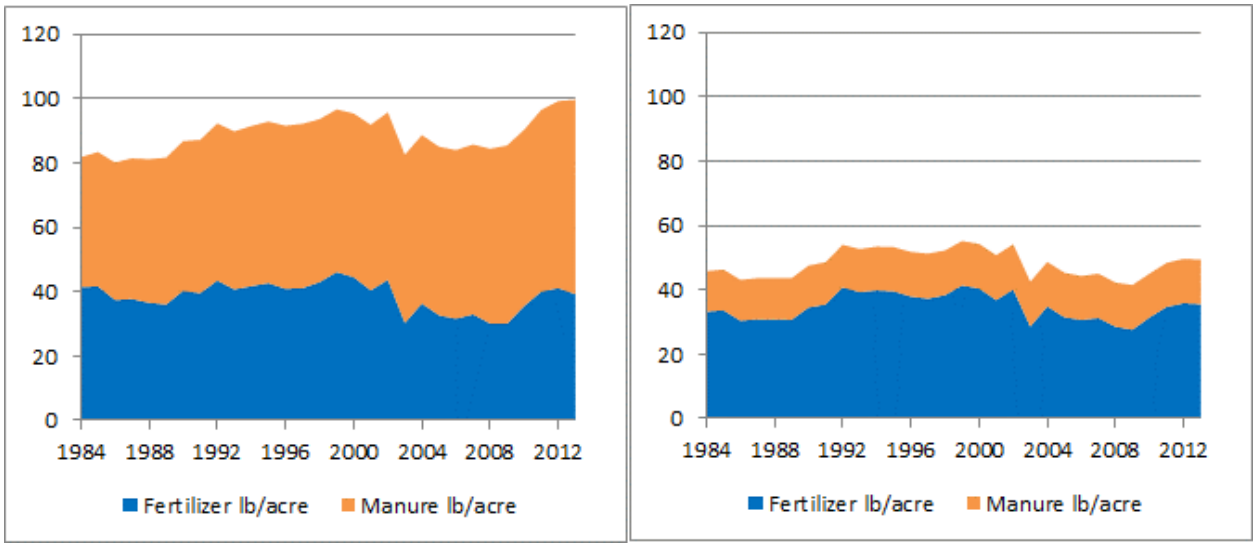
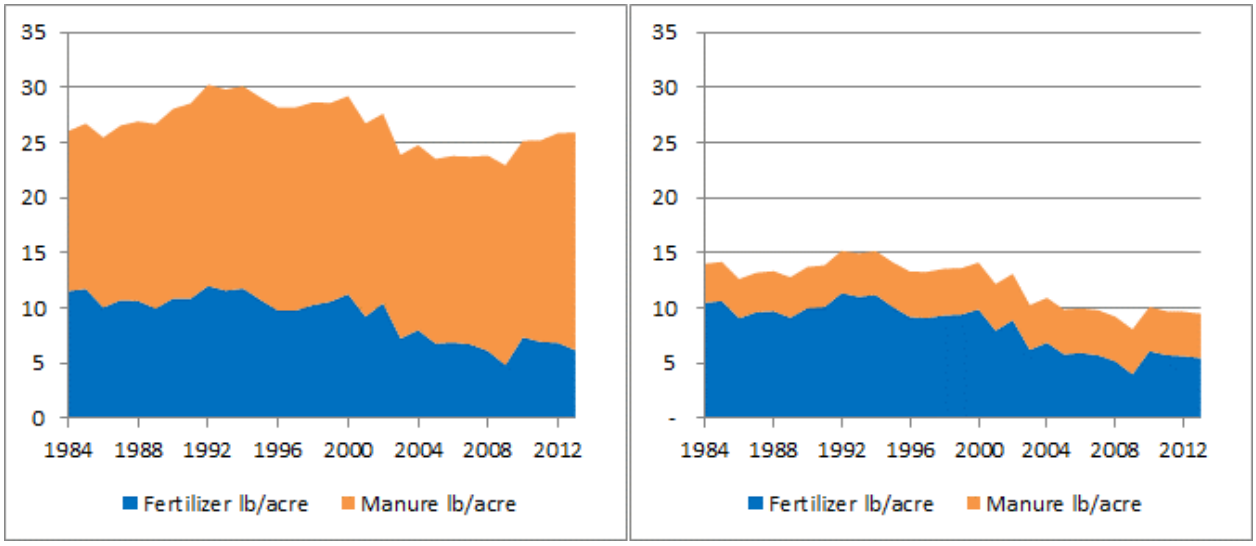


Figure 4. Phosphorus applied to cropland as manure and fertilizer in the four focus counties (left) and the rest of the Commonwealth (right)[29]



c. Animal production

It is not surprising that the four focus counties land-apply more manure than the rest of Pennsylvania, because these counties have more intensive animal production. The intensity of animal production in parts of Pennsylvania (and in other parts of the country) is typically associated with a relatively large number of Concentrated Feeding Operations (CAFOs). CAFOs consist of large barns full of tightly-packed animals with little or no access to natural

pasture. CAFOs may also have crop fields for the land-application of manure, but much of the waste generated by a CAFO is shipped offsite and land-applied elsewhere (though usually within the same county). About 28 percent of the animal production in Pennsylvania happens at CAFOs.[30] Most of this happens in the four focus counties.[31] Overall, about 40 percent of Pennsylvania CAFOs are in the four focus counties,[32] and these operations are responsible for nearly 60 percent of CAFO animal inventories in the Pennsylvania part of the Chesapeake Bay Watershed, as shown in **Tables 6 and A9**. Note that over half of the CAFO animals in Pennsylvania's part of the watershed are in Lancaster and Lebanon Counties.

The breakdown of animal production by animal type is shown in **Table 7**. The four focus counties clearly have a much higher density of animals relative to the amount of land available for manure application. For every agricultural acre in the four focus counties, there are twice as many turkeys, three times as many dairy cows, and roughly six times as many chickens as there are elsewhere in the Commonwealth. In other words, there is much more manure produced in the four focus counties relative to the amount of land suitable for manure application. Like the rest of the state, these four counties have seen an increase in animal production over time, as shown in **Appendix A, Table A10**. For example, broiler production has increased by 44 percent since the mid-1980s, turkey production has increased by 70 percent, and hog production has nearly doubled. Manure production has increased in tandem, as shown in **Appendix A, Table A11**. Since the mid-1980s, the production of broiler litter in the four focus counties has increased from roughly 65,000 wet tons per year to over 110,000 dry tons per year; the amount of hog manure has doubled from 700,000 tons per year to 1.4 million tons per year. Dairy inventories and manure production, which account for a large fraction of total manure production in a county, have increased by 16 percent in the four focus counties while they have declined by 27 percent everywhere else (**Tables A10 and A11**).

Table 7. Animal production details (for 2013)[33]

	Number of animals		Animals per agricultural acre	
	4 focus counties	Other counties	4 focus counties	Other counties
Beef	12,027	80,350	0.02	0.02
Dairy	191,958	281,056	0.29	0.09
Hogs and pigs	870,806	894,128	1.3	0.3
Broilers	91,227,719	82,658,295	138.4	25.3
Layers	15,316,811	9,336,038	23.2	2.9
Pullets	4,341,303	2,511,939	6.6	0.8
Turkeys	1,974,239	4,701,948	3.0	1.4

d. Manure transport

The relationship between animal production in a given county and the land application of manure in that county is not necessarily direct. Farmers routinely sell manure for use as

fertilizer on other farms. But as mentioned previously, when manure is shipped off-site, it usually does not go very far.

EIP obtained manure transport data from the Pennsylvania Department of Environmental Protection (DEP), covering the period from June 2011 through June 2016.[34] For 25 percent of the transferred tons, the destination was unknown. Of the transfers with a known destination, 89 percent of the transferred tons stayed within the county of origin and an additional 4 percent was shipped to both the county of origin and another county (presumably to farms that straddle county lines); for example, a January 2015 transfer of chicken litter from Adams County went to "Adams/York." The four focus counties and the rest of the Commonwealth are nearly identical when it comes to patterns of manure transport (see **Table 8** below). In short, the manure transport data support the assumption that almost all of the manure and litter generated in a county stays in that county.

Table 8. Manure transfers in Pennsylvania, 2011-2016 (tons)[35]

	Four focus counties	Other counties
Transferred within county	637,353	1,389,625
Transferred to multiple destinations, including county of origin[36]	21,208	80,234
Transferred out of county	32,163	107,315
Transferred to unknown destination	363,883	409,192
In-county transfers as fraction of transfers with known destination[37]	**95%**	**93%**

e. Over-applied nitrogen and phosphorus

As a result of the patterns described above – too many animals for the amount of cropland available for manure application, and limited transport of manure out of the county of origin – the four focus counties are systematically over-applying nutrients to cropland. This problem is not unique to the four focus counties, but it is particularly egregious in these counties. **Table 9** shows the amount of nitrogen and phosphorus applied to each acre of cropland in 2013, along with estimated crop uptake (note that cropland is a subset of agricultural land, so results differ from those presented in Table 6 above). For nitrogen, over-application is routine across the state. Outside of the four focus counties, 12 percent of land-applied nitrogen is lost to the local environment. In the four focus counties the problem is more acute – 18 percent of land-applied nitrogen, or 34 pounds per crop acre, is lost to the environment. For phosphorus, there was very little over-application outside the four focus counties in 2013. Within the four counties, however, 37 percent of land-applied phosphorus was lost to the environment. These numbers probably underestimate true over-application because they do not account for nutrients available to crops before any additional fertilizer or manure is applied. But at a minimum, for every acre of cropland in the four focus counties, 34 pounds of nitrogen and 15 pounds of phosphorus were added to the soil, not taken up by crops, and either accumulated in soil or leaked out into the local environment in

2013. This adds up to nearly 14 million pounds of nitrogen, and over 6 million pounds of phosphorus, lost to the environment from just four counties in one year.

It bears repeating that in these four counties, unlike the rest of the state, most of the land-applied nitrogen and phosphorus comes from manure. Since crops are clearly not using all of the manure nutrients, it is hard to justify the intensive manure applications as fertilization. Instead, land application functions more as waste disposal for the growing animal production industry. As we describe in Section 3, this is largely unregulated waste disposal. Like any other unregulated waste disposal practice, runaway manure application creates serious environmental contamination, in this case impaired water quality, as described in Section 4 below.

Table 9. Nutrients applied to cropland in 2013[38]

	Four Focus Counties	The rest of Pennsylvania
Cropland with nitrogen applications (acres)	412,493	1,634,759
Nitrogen applied (lb/acre)	186	117
Crop uptake (lb/acre)	152	103
Net loss (lb/acre)	34	14
Net loss (lbs)	13.8 million	22.7 million
Net loss (% of applied)	18%	12%
Cropland with phosphorus applications (acres)	411,734	1,634,421
Phosphorus applied (lb/acre)	40	17.18
Crop uptake (lb/acre)	25	17.15
Net loss (lb/acre)	15	0.03
Net loss (lbs)	6.1 million	45,092
Net loss (% of applied)	37%	0.2%

f. Ammonia deposition

The concentration of animals and animal waste in the four focus counties creates an additional source of nitrogen pollution in the form of ammonia deposition. Gaseous ammonia is emitted from livestock and poultry barns, from manure storage areas, and from land-application fields. Although there are other sources of ammonia in the air, most atmospheric ammonia comes from agriculture. According to the most recent National Emissions Inventory, out of a national total of 3.9 million tons of ammonia that are emitted each year, 1 million comes from synthetic fertilizer and 2.2 million comes from animal waste.[39] Atmospheric ammonia does not travel far (relative to other atmospheric sources of nitrogen like nitrites and nitrates), which means that ammonia deposition tends to be concentrated in areas where agricultural sources are concentrated. This can be seen in the Chesapeake Bay Watershed Model input data, where Lancaster and Lebanon Counties have the highest ammonia deposition rates in the entire Chesapeake Bay watershed

(including other states).[40] The mean ammonia deposition rates for the full watershed and for Pennsylvania were 3.1 and 3.4 pounds per acre, respectively, in 2014 (the most recent available data).[41] In Lancaster and Lebanon Counties, ammonia is deposited at rates of 9.4 and 8.9 pounds per acre (see **Appendix A, Table A12**). For the four focus counties as a group, the ammonia deposition rate is 7.1 pounds per acre. In the aggregate, roughly 11 million pounds of nitrogen are deposited in the four focus counties each year. Actual deposition may be even higher than these estimates suggest, because model assumptions about ammonia emissions from animal barns are outdated and potentially too low. For example, a recent EPA monitoring study of a 21,000-broiler CAFO barn found 4.1 tons of ammonia emitted in a year.[42] A separate, independent model estimated that a barn with the same characteristics would emit 4.9 tons in a year.[43] The EPA model used by the Chesapeake Bay Program, by contrast, would assume that emissions were roughly half that, at 2.3 tons.[44]

g. Summary of agricultural hot spots

All of the evidence discussed above points to a critical conclusion: Animal production in the four focus counties is more intensive than the land can support, and now exceeds the carrying capacity of the landscape. These animals generate a huge volume of manure and litter, and most stays within county lines. As a result, the amount of manure applied to cropland has increased along with animal numbers. The average acre of cropland in these counties receives twice as much nitrogen, and nearly three times as much phosphorus, as an acre of cropland elsewhere in Pennsylvania. This is simply unsustainable. As discussed below, these manure applications are largely unregulated, with much of the land-applied nutrient content lost to the environment, creating local water quality impairments and, ultimately, impairing the health of the Chesapeake Bay.

3. Nutrient management regulations: Lax, voluntary, and ineffective

a. Regulatory framework

Nutrient management in Pennsylvania, and specifically the land-application of manure, is regulated in different ways for different types of operation:

- The least rigorous standards revolve around Manure Management Plans (MMPs), and apply to all operations that land-apply manure.
- More rigorous state requirements apply to Concentrated Animal Operations (CAOs). CAOs are defined as operations with more than eight "Animal Equivalent Units," or AEUs, and more than two AEUs per acre of land suitable for manure application.[45] AEUs are effectively the same as Animal Units, both being equal to 1,000 pounds of

animal weight, regardless of the type of animal.[46] CAOs are therefore operations with more than 8,000 pounds of animals above a certain density. Roughly 5 percent of Pennsylvania's animal operations are CAOs.[47] CAOs are required to develop and follow Nutrient Management Plans (NMPs).

- Large CAOs, and other operations that fit the federal definition of a Concentrated Animal Feeding Operation (CAFO), are subject to federal Clean Water Act requirements. CAFOs, like CAOs, must have and follow NMPs for land-application of manure.

- Finally, all farms that disturb more than one-tenth of an acre should have and follow erosion and sediment control plans to minimize the loss of topsoil. However, as discussed below, this is more of a suggestion than a requirement.

There are two major problems with this framework, discussed in more detail in the sections that follow. First, there is little or no enforcement of manure management regulations. This means that MMPs and even NMPs are effectively voluntary. Second, the regulations allow for the application of much more nitrogen and phosphorus than crops can use. As a result, even farmers who comply with the regulations may be over-applying nutrients.

I. MANURE MANAGEMENT PLANS

Pennsylvania's Clean Streams Law establishes a short list of requirements for agricultural operations that are not CAOs or CAFOs.[48] The primary requirement of the law is that all operations that land-apply manure must have and follow Manure Management Plans (MMPs) based on Pennsylvania's Manure Management Manual.[49] The Manual lays out the following guidelines for MMPs:

- Farmers can write their own MMPs, and are not required to have them approved.

- Land application generally has to adhere to a 100-foot setback from surface water, though this can be reduced if a stream is not flowing, if soil phosphorus is lower than 200 ppm, or if there is a vegetated buffer along the waterway.

- The Manual sets some restrictions on winter land application, as discussed more fully below.

- Farmers are given three choices for establishing manure application rates. The simplest option is to use one of two sets of charts attached to the manual. The first is for fields with soil phosphorus levels below 200 ppm. On these fields, farmers can land-apply to meet crop nitrogen need. The second set of charts is for fields with more than 200 ppm phosphorus, or unknown soil phosphorus levels. These charts provide application rates based on the amount of phosphorus that growing crops will remove from the soil. Both sets of charts consider crop type, expected yield ("realistic optimistic crop yield"), type of manure (e.g., broiler, liquid dairy, solid dairy), land

application timing (season), and method of manure incorporation. The charts do not consider soil nutrient content, prior crops grown on a field, or factors that might contribute to phosphorus runoff, such as runoff potential and distance to streams.

II. NUTRIENT MANAGEMENT PLANS

Manure applications at CAOs are governed by Pennsylvania's Nutrient Management Act and its implementing regulations.[50] CAOs are required to develop and implement Nutrient Management Plans (NMPs).[51] NMPs are prepared by certified nutrient management specialists and reviewed and approved by the County Conservation District (CCD) or the State Conservation Commission (SCC).[52] Each NMP must include, among other things:

- Information about the amount, type, and nutrient content of manure or litter to be land-applied.[53]
- Information about residual soil nitrogen left over from previous legume crops.[54]
- The types and expected yield of crops to be grown on land-application fields. Expected yields must be "realistic," and if actual yields do not average 80 percent of expected yield after three years, the NMP must be adjusted to reflect actual yield.[55]
- Soil test data (for phosphorus, potassium, and pH).[56]
- Details about manure application rates. These rates must take into account the nutrient content of the manure, expected crop yields, residual soil nitrogen from past crops, and the application of starter fertilizer and any other synthetic fertilizer.[57]
- Details about the timing and method of land applications, including the use of any Best Management Practices (BMPs), which should collectively "hold the nutrients in place for crop growth, and protect surface water and groundwater."[58]
- The regulations also require setbacks from surface water bodies and wells, and some minimal restrictions on land applications in winter and in-field stacking of manure.[59]

In addition, when necessary to minimize the risk of phosphorus runoff, NMPs must limit phosphorus applications to the amount that crops will take up.[60] Phosphorus application is prohibited if surface water impacts cannot be "managed" by limiting the nutrients based on phosphorus uptake. The regulatory language is vague about when and how farmers should manage phosphorus runoff risk, but one option for complying with these requirements is to use Pennsylvania's Phosphorus Index, described below.[61] In addition to CAOs, some operations may voluntarily adopt NMPs in order to take advantage of financial assistance programs. These are known as Voluntary Agricultural operations, or VAOs. As of 2014, there were roughly 1,200 VAOs in the Pennsylvania portion of the Bay watershed, slightly more than the number of CAOs. However, the number of VAOs has been decreasing, particularly in Lancaster, Lebanon and Union Counties, as farmers switch to more lenient MMPs.[62]

III. CAFOS

CAOs with more than 300 animal units (AEUs), and any operation with more than 1,000 animal units, is defined as a Concentrated Animal Feeding Operation (CAFO).[63] CAFOs are required to obtain federal wastewater permits, known as National Pollutant Discharge Elimination System permits, and are required to have and follow NMPs. As with CAOs, these NMPs must be prepared by certified nutrient management specialists and reviewed and approved by a CCD or the SCC.[64] Unlike CAOs, however, CAFOs must submit their NMPs to the Pennsylvania DEP for approval.

IV. THE PHOSPHORUS INDEX

In some cases, farms that are vulnerable to phosphorus runoff must restrict their phosphorus applications by using a tool called the Phosphorus Index. The Phosphorus Index is a worksheet-based formula for deriving a single score from multiple pieces of information, including soil phosphorus levels, manure and fertilizer application details, runoff potential, distance from surface water, and the presence or absence of a vegetated buffer.[65] Depending on the score, manure applications may be limited to the amount of phosphorus that crops can take up, or may be prohibited altogether. Generally speaking, operations with NMPs should be using the Phosphorus Index, though not all of these operations will be required to restrict their phosphorus applications: Fields with a "low" or "medium" score can apply manure to meet nitrogen need. [66] As we describe in Section 3(c) below, when farmers apply manure to meet nitrogen needs, they are usually over-applying phosphorus.

V. EROSION AND SEDIMENT CONTROL PLANS

All farms that disturb more than one-tenth of an acre through plowing, tilling, or heavy animal use, are formally required to have and implement Erosion and Sediment Control Plans ("Erosion Plans"), and all farms that disturb any amount of soil should implement erosion control Best Management Practices.[67] Erosion Plans can be prepared by the Natural Resources Conservation Service, a CCD, or a private consultant, and must be kept on-site, but are not subject to approval by any agency. As discussed below (section 3(b), Lack of Enforcement), the erosion and sediment control regulations are treated more like suggestions than regulations.

VI. MANURE TRANSFERS

Manure exported from CAOs and CAFOs to neighboring farms is subject to even less care and oversight in Pennsylvania than on-site land applications. A limited set of regulations creates a paper trail between manure exporters and importers (or intermediary haulers and brokers), requires a nutrient balance sheet for land application at the importing farm, and incorporates some of the NMP requirements regarding manure application rates and setbacks.[68] Records related to manure application must be kept by the entity that does the applying, whether that's the exporter (or a manure hauler under contract to the exporter), the importer, or a broker.[69]

It is unclear whether or to what extent these requirements are followed. There appears to be confusion about whether anything more than a Manure Management Plan is ever required for an importing farm.[70] There also appears to be little or no enforcement of the requirements that apply to manure haulers and brokers. In 2013, for example, there were

"no field-related compliance and enforcement activities" for the hauler and broker program.[71] Overall, given the attenuation between manure source and manure destination, the complex paper trail, and the lack of regulatory oversight, it appears that exported manure is effectively exempt from the requirements that apply to the manure source. This may be why, according to EPA, some CAFO owners "have incorporated as different entities on adjacent land parcels in order to possibly avoid [Clean Water Act] permit coverage."[72] CAFO permits require NMPs for land application of manure, and it may be much easier for CAFO owners to "export" the manure to fields that have no effective restrictions.

VII. STREAM FENCING

One of the easiest ways to reduce manure pollution is to keep livestock out of streams. This is generally done through stream fencing, alternative sources of water, or both.[73] As absurd as it may sound, under Pennsylvania law the Commonwealth is not allowed to require stream fencing.[74] This may change – two house bills introduced in 2017 would repeal that provision[75] – but for now the Commonwealth's hands are tied. Instead, Pennsylvania has tried to encourage voluntary stream exclusion. As part of that effort, and pursuant to its obligations under the Bay TMDL, Pennsylvania set a target of roughly 200,000 acres for "pasture management," including subsidiary targets of 16,617 acres for "stream access control with fencing" and roughly 100,000 acres with alternative watering.[76] Although the Commonwealth has made some progress, as of 2016 it was still 26 percent behind its 2015 target for stream fencing, 30 percent behind its 2015 target for alternative watering, and 36 percent behind its 2015 target for pasture management overall.[77]

VIII. WINTER MANURE SPREADING

Another simple way to reduce manure pollution is to prohibit the spreading of manure during the winter, when the ground is hard or frozen and less able to absorb nutrients. This is not unheard of in the Chesapeake Bay watershed – both Delaware and Maryland prohibit winter manure spreading.[78] In Pennsylvania, however, winter spreading is only subject to minimal restrictions including 100-foot setbacks from water, a requirement that the field have 25 percent crop residue or a cover crop, and a requirement that the field have less than 15 percent slope.[79] Farmers following MMPs may still apply up to 3 tons of dry poultry litter, 20 tons of non-dry poultry manure, or 5,000 gallons of liquid manure per acre during winter months as long as they meet these minimal restrictions.[80] Although the U.S. EPA has urged Pennsylvania to further restrict winter applications, and the Commonwealth may be considering a prohibition,[81] for now this reckless manure handling practice is allowed.

b. Lack of enforcement

Pennsylvania's manure management rules are largely unenforceable or unenforced. The most rigorous standards, and presumably the rules most likely to be enforced, apply to CAFOs. The Pennsylvania DEP is theoretically responsible for enforcement of CAFO NMPs, but EPA has found significant problems with DEP's oversight. As noted above, NMPs are frequently inaccurate, and EPA concluded that "there is no assurance that an NMP submitted with a CAFO application, which was developed by a certified planner, will be accurate, complete, and current."[82]

The regulations governing NMPs at CAOs and other operations are supposed to be enforced by the County Conservation Districts (CCDs) and the State Conservation Commission (SCC). Enforcement appears to be lax. All records are kept on-site by the operation, not submitted to the CCD or the SCC.[83] CCDs inspect CAO NMPs annually and are authorized to refer noncompliant operations to the SCC for enforcement. In practice, according to EPA, the CCDs utilize a "three strikes policy" before referring non-compliance to the SCC, grant compliance schedules of up to a year, and as a result, rarely make referrals to the SCC (there were five in 2013).[84]

A further problem with NMPs is that they are often inaccurate or incomplete. CCDs in Union, Snyder, and Lebanon Counties have all stated that certain private sector certified nutrient management planners consistently develop "bad plans."[85] EPA also observed incomplete NMPs during its review.[86] The SCC could, but has not, revoked the certification of these planners.[87]

Most operations are only required to have MMPs, and this is for all practical purposes a voluntary program. The CCDs are not authorized to enforce manure management regulations.[88] Neither PA DEP nor the CCDs appear to know how many operations have MMPs.[89] Farmers can write their own plans, and there is no approval process. Many farmers simply ignore the requirement altogether: In 2009, EPA inspected 24 farms in Lancaster County and found that only 4 had MMPs.[90] As of 2016, Pennsylvania DEP estimated that only 30 percent of farms in the state had the required plans.[91] The situation may be improving – a more recent inspection survey found that "approximately 60 percent of farmers met their requirements to have manure management plans, erosion and sediment control plans, or both."[92] There is still much room for improvement however, and the recent inspections did not evaluate compliance with MMPs.

Finally, Erosion Plans, like MMPs, are effectively voluntary. No agency is responsible for approving Erosion Plans, and the plans do not have to be updated or revised on a fixed schedule.[93] The CCDs do not tend to review implementation of Erosion Plans, only their presence or absence. The Lebanon County CCD has stated that farmers rarely have Erosion Plans, though that may be improving according to the recent state-wide inspections mentioned above. The EPA observed that CCDs rarely check Erosion Plans for consistency with NMPs (at farms where both are required). When EPA reviewed CAFOs in 2013 it found "significant inconsistencies" between Erosion Plans and NMPs. Overall, according to EPA, Pennsylvania "does not have a consistent approach or sufficient resources to ensure applicable operations are meeting [agricultural erosion and sediment] requirements."[94] In short, there does not appear to be a reliable regulatory safeguard against erosion and soil loss.

EPA has repeatedly warned Pennsylvania that it is not on track to meet TMDL targets for agricultural pollution, and specifically flagged inadequate nutrient management implementation and lax enforcement.[95] In response, Pennsylvania recently launched a "reboot" strategy to ramp up efforts in compliance, data tracking and reporting, and provide targeted funding for Best Management Practice implementation in an effort to meet its 2025 TDML goals.[96] These are important steps to take, but it is not clear whether Pennsylvania has, or will continue to have, the resources necessary to carry out this strategy. The

Pennsylvania Department of Environmental Protection, in particular, continues to face devastating budget cuts, and has gone from a budget of $246 million in 2002 to the current 2017-2018 proposal of $148 million.[97]

A more fundamental problem is that a fully-funded reboot strategy would only get Pennsylvania part of the way. This is because the existing legal framework, even if perfectly complied with and enforced, is not adequately protective of water quality. The next section addresses this issue in more detail.

c. Over-application is the standard recommendation

Even when farmers are following the rules, they may be contributing to ongoing water quality problems, because Pennsylvania's manure management regulations authorize the over-application of animal waste. The following discussion is focused mainly on Manure Management Plan (MMP) requirements, because these are the most widely applicable.

To begin with, MMPs are based on forward-looking estimates of "realistic optimistic crop yield."[98] When actual crop yield is less than desired, the unused excess nitrogen and phosphorus from manure applications can – and often does - leave the field as pollution. While NMPs must be corrected if actual yield does not meet expected yield, there is no such requirement for MMPs.

Second, recommendations intentionally exceed crop need due to the fact that much of the nitrogen and phosphorus applied in manure is "lost", through volatilization of ammonia, runoff, or by leaching below the root zone in the soil, before it can be used by growing crops.[99] When nitrogen and phosphorus are "lost," they become pollution.

Consider the example of poultry litter from broilers being land-applied to corn grain cropland. According to the Chesapeake Bay Program, a ton of broiler litter contains approximately 91 pounds of nitrogen and 31 pounds of phosphorus.[100] According to Pennsylvania's Manure Management Manual, the nitrogen-based application rates for broiler litter on corn grain fields range from 2 to 4 tons per acre, depending on expected yield (bushels per acre) and when and how the litter is incorporated into the soil. A 2-ton recommendation is rare, and is limited to spring applications that are incorporated within one day on fields that are expected to have relatively low yields. A 4-ton recommendation is much more common. Recommended applications in the fall, or in the spring if the litter is not incorporated into the soil, are 4 tons per acre across the board – regardless of expected crop yield. Recommendations for spring applications that are incorporated within one week are also generally 4 tons per acre.[101] Four tons of broiler litter contain 364 pounds of nitrogen and 122 pounds of phosphorus. The most common recommended rate of broiler litter application to corn grain fields is therefore 364 pounds/acre (nitrogen) and 122 pounds/acre (phosphorus).

How much does grain corn actually need? According to Penn State's Cooperative Extension office, an acre of grain corn needs between 100 and 220 pounds of nitrogen,[102] and between 17 and 35 pounds of phosphorus.[103] This is much less than the amount in the recommended applications.

Here is a second, more detailed example. Consider two grain corn fields, one high-yield and the other low-yield. The high-yield field is expected to produce 220 bushels of corn per acre, while the low-yield field is expected to yield 100 bushels of corn per acre. **Table 10** provides a comparison between application recommendations and crop need. Note that these recommendations are based on a crop's nitrogen needs. The balance of nutrients in manure is not the same balance of nutrients that crops require. The amount of manure required to meet a crop's nitrogen needs will almost always contain more phosphorus than the crop needs.[104] When manure is over-applied from a nitrogen perspective, there is an even greater over-application of phosphorus.

Table 10. Recommended rates of broiler litter application to corn grain fields compared to actual crop need.

Expected yield	High-yield field 220 bushels per acre			Low-yield field 100 bushels per acre		
Application rates[105]	Tons/acre	Nitrogen lbs/acre	Phosphorus lbs/acre	Tons/acre	Nitrogen lbs/acre	Phosphorus lbs/acre
Spring Incorporation within 1 day	3	273	92	2	182	61
Spring incorporation within 1 week	4	364	122	3	273	92
Spring no incorporation	4	364	122	4	364	122
Fall	4	364	122	4	364	122
Winter with cover crop	3	273	92	3	273	92
Winter no cover crop	3	273	92	3	273	92
Crop need[106]		220 lbs/acre	35 lbs/acre		100 lbs/acre	17 lbs/acre

In short, farmers following the Manure Management Manual for the application of broiler litter to grain corn fields may be applying three times more nitrogen than the corn needs, and seven times more phosphorus than the corn needs. The same is generally true for other crops as well – farmers following the Manure Management Manual are likely over-applying nitrogen and phosphorus by substantial amounts.

Another way in which the Manure Management Manual authorizes over-application is by ignoring prior land use and the availability of nutrients in the soil. For example, legume crops like alfalfa fix atmospheric nitrogen in the soil. According to Penn State, if a corn crop is planted after an alfalfa crop, it only needs a small starter application; the rest of its nitrogen needs are met by the nitrogen that was fixed by the alfalfa.[107] The Manure Management Manual recommends manure applications in a forward-looking way, considering crop uptake only and ignoring existing soil fertility.

Phosphorus can build up in soil over time, and many crop fields already have more than enough phosphorus to support a healthy crop *before* any manure is added. For example, according to Virginia's nutrient management criteria, soils with phosphorus concentrations above 127 ppm[108] do not need any additional phosphorus. Yet the Manure Management Manual authorizes, and even recommends, the application of manure to all fields, including fields with more than 127 ppm phosphorus. If soil phosphorus levels are below 200 ppm, the Manual recommends the application of manure to meet nitrogen needs. Manure applied to meet nitrogen needs automatically adds more phosphorus than crops can take up,[109] so this results in an extreme over-application of phosphorus. Even if soil phosphorus levels exceed 200 ppm, the Manure Management Manual only requires that manure applications be limited to the amount of phosphorus that the crop can take up. But again, the soil doesn't need any more phosphorus, and most or all of the added phosphorus is wasted.

d. Options for more efficient manure utilization

There is not enough cropland in the four focus counties to safely absorb the amount of manure that the counties generate. Through either a reduction in animal numbers or a more aggressive effort to export manure away from the region, the amount of land-applied manure in these counties must decline. One way to facilitate this change without sacrificing crop production is to more efficiently utilize manure.

Penn State has identified several manure application practices for optimal delivery of nitrogen to crops with minimal loss, including:

- Incorporate manure immediately after spreading to minimize volatilization.[110]
- Apply manure as close to the time of crop need as possible.[111] If poultry litter is applied in the fall before a crop with no cover crop, 85 percent of the nitrogen is lost. If litter is applied in the spring and immediately incorporated, only 25 percent is lost.[112]
- Rotate legumes into the crop mix to reduce the need for fertilizer.[113]
- Use a test known as the "pre-sidedress soil nitrate test" (PSNT), which is conducted when corn is 12 inches tall, to determine exactly how much nitrogen a crop actually needs.[114]
- Keep records of actual crop yield.[115]

In order to minimize phosphorus over-application and loss, at a minimum, all farms should be required to use Pennsylvania's Phosphorus Index.

These and other techniques are captured in a suite of Best Management Practices known as "Supplemental Nutrient Management" in the forthcoming Phase 6 Chesapeake Bay watershed model.[116] Specific practices that the Bay Program counts toward reductions in nitrogen and phosphorus loss include:

- Various nitrogen tests, including the PSNT (identified above), the corn stalk nitrate test, the Illinois Soil Nitrogen Test, and the Fall Soil Nitrogen Test.
- Annual manure analysis
- Ammonia loss assessment and modeling
- Split applications
- Subsurface injection or incorporation
- Use of the phosphorus index
- Phosphorus removal-based manure rates

There is overlap between these specific techniques. For example, a farmer using the Phosphorus Index will sometimes be required to use phosphorus removal-based manure rates, and the use of a PSNT or corn stalk nitrate test goes hand-in-hand with split applications. Farmers using a combination of these practices are able to maximize the amount of land-applied nutrients going to crops and minimize loss to the environment.

4. Agriculture and local water quality

Nutrient runoff from land-applied manure is a problem for the Chesapeake Bay, but it is also a problem for local water quality. This can be seen in water monitoring data, and in the Pennsylvania DEP's assessment of impaired rivers and streams.

a. Water quality data

As nitrogen and phosphorus increase in surface water, they present risks to aquatic life by fueling the growth of algae, and then the depletion of oxygen as the algae die and decompose. Pennsylvania does not have water quality standards for nitrogen and

phosphorus. Virginia, however, uses threshold values above which nitrogen and phosphorus levels are "suboptimal." These threshold values, 2 mg/L (nitrogen) and 0.05 mg/L (phosphorus),[117] are similar to water quality standards established by other states across the country.[118]

There are two sources of data that can be compared to these thresholds. First, the U.S. Geological Survey maintains a long-term database of monitoring stations throughout the Chesapeake Bay Watershed.[119] There are four such stations relevant to the four focus counties:

- Stations in Conestoga and Martic Forge, PA monitor water that drains from Lancaster County into the Susquehanna River.
- A station on the West Branch of the Susquehanna in Lewisburg monitors water that drains from Union County (and other counties).
- A station in Fairview, MD, just south of the state line, monitors water in Conococheague Creek, draining from Franklin County.

Figures 5 and 6 below show the data for these four stations. Although average concentrations have been declining over the long term, they remain far above healthy levels in Lancaster County and in Conococheague Creek. The two Lancaster County stations show increases in phosphorus concentrations in recent years.

Figure 5: Total Nitrogen data from USGS Stations near the four focus counties.[120]

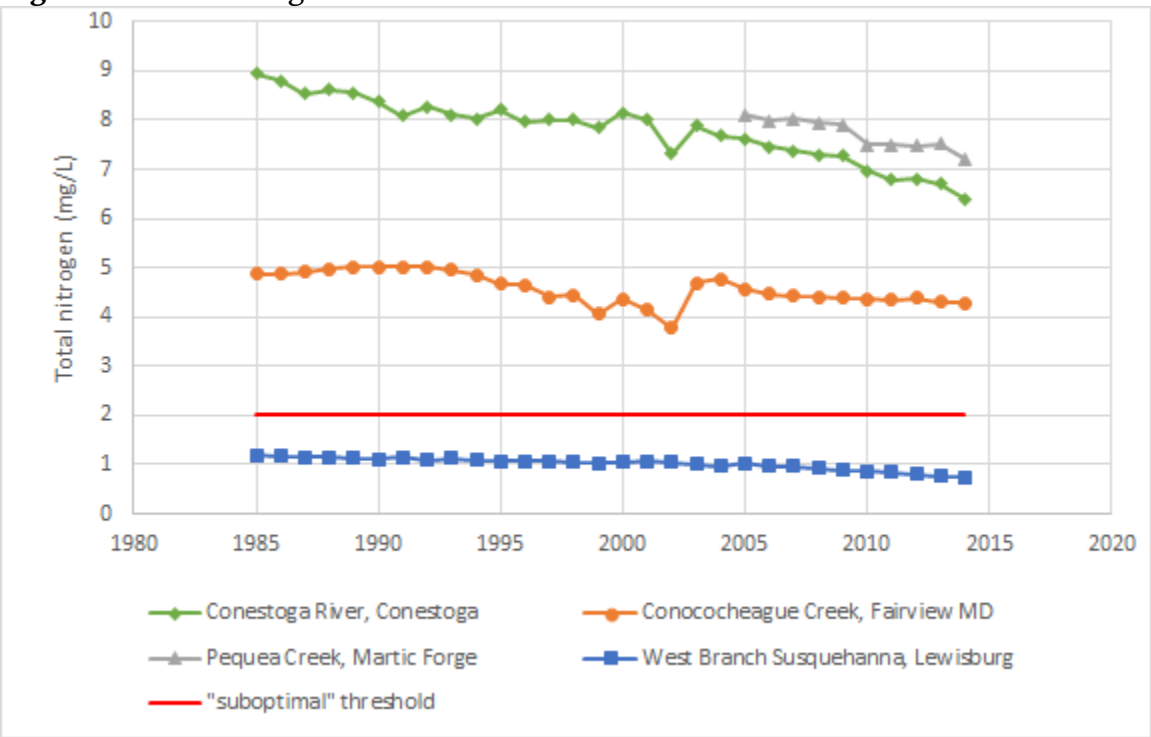
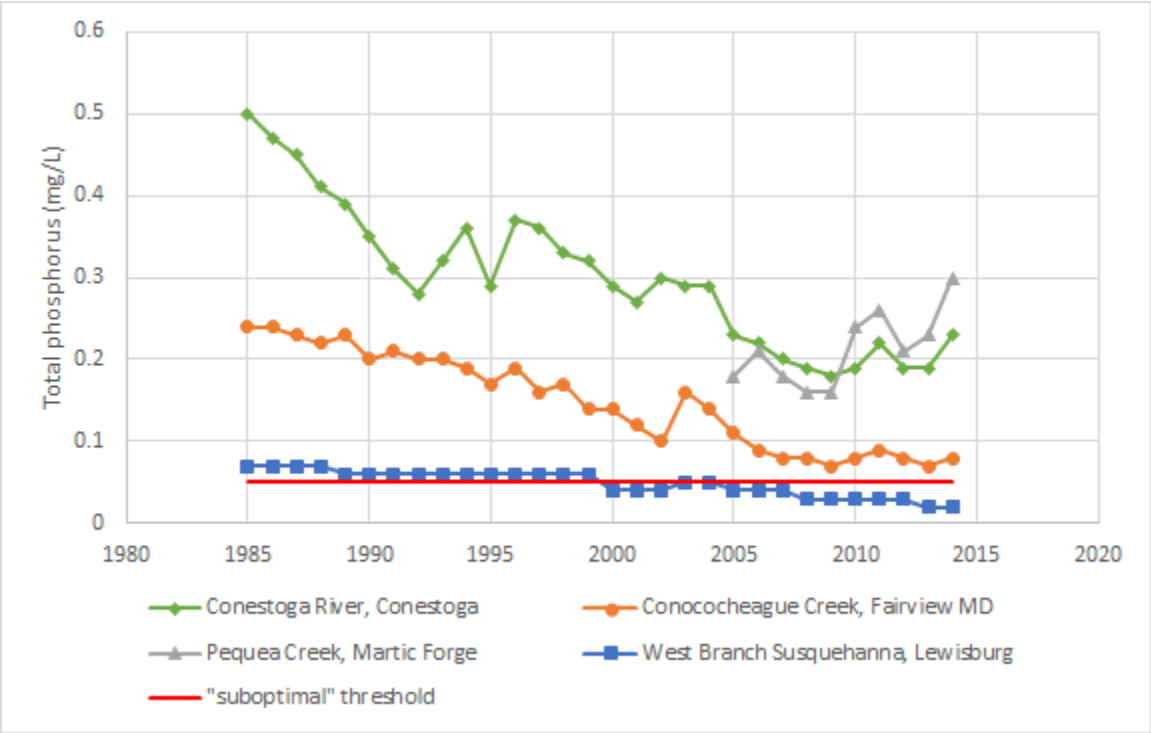


Figure 6: Total Phosphorus data from USGS Stations near the four focus counties.[121]



A second source of data is Pennsylvania DEP's water monitoring database, which covers the 2012-2016 time period. Most of the monitoring stations in this database are in Lancaster County. As shown in **Appendix B,** and summarized in **Figures 7 and 8** below, most of these stations show unhealthy levels of both nitrogen and phosphorus. This is true during both routine sampling and sampling during storm events. The phosphorus data show that streams during storm events generally have 3-4 times more phosphorus than normal stream water. This suggests that soil runoff from crop fields continues to be a major source of phosphorus and a major problem.

Figure 7: Total nitrogen sampling data from Pennsylvania DEP, 2012-2016. The mean values shown here only include routine sampling (no sampling from storm events). Virginia's threshold for "suboptimal" total nitrogen levels is 2 mg/L. There were no total nitrogen data for Franklin County. See Appendix B for more detail.

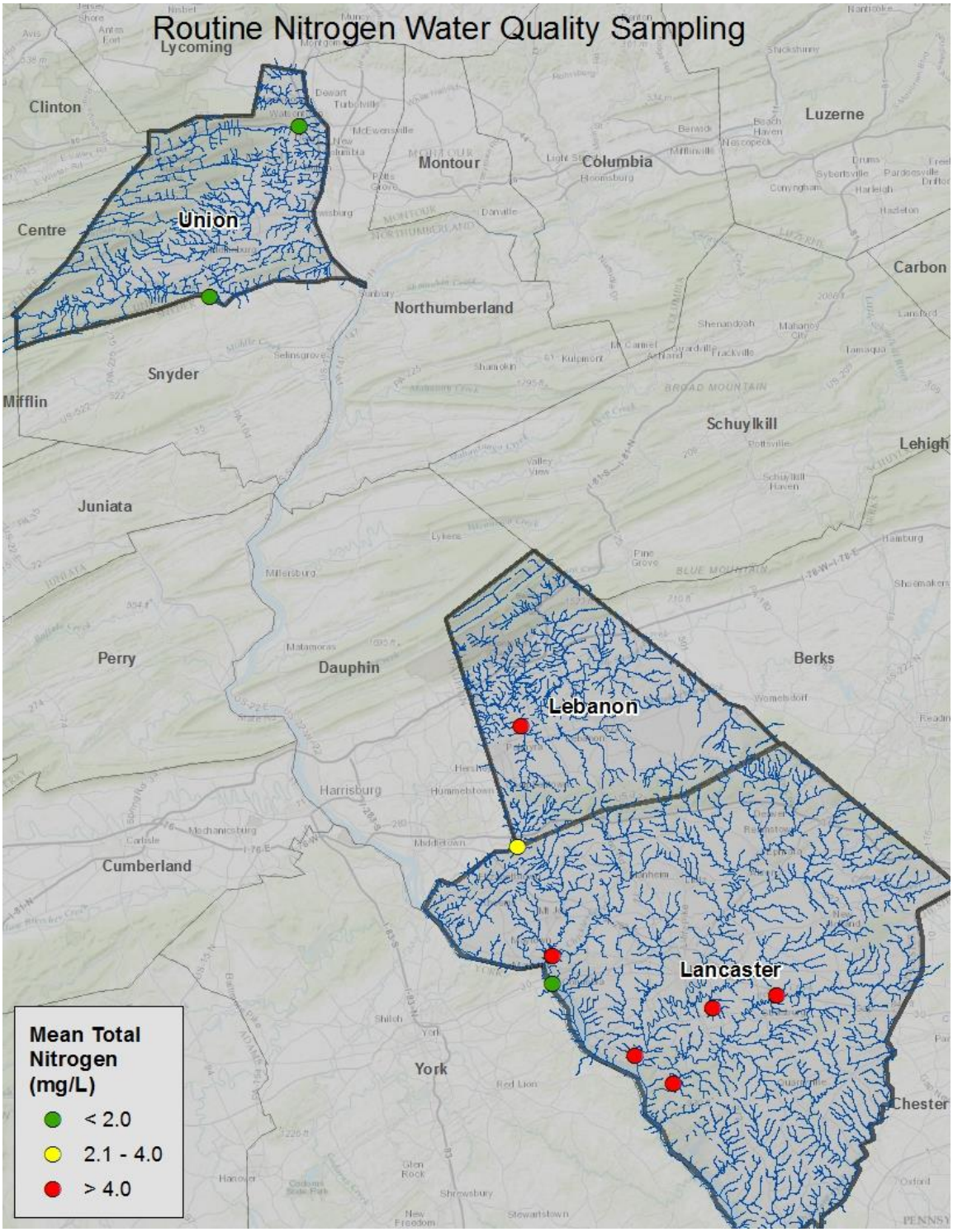
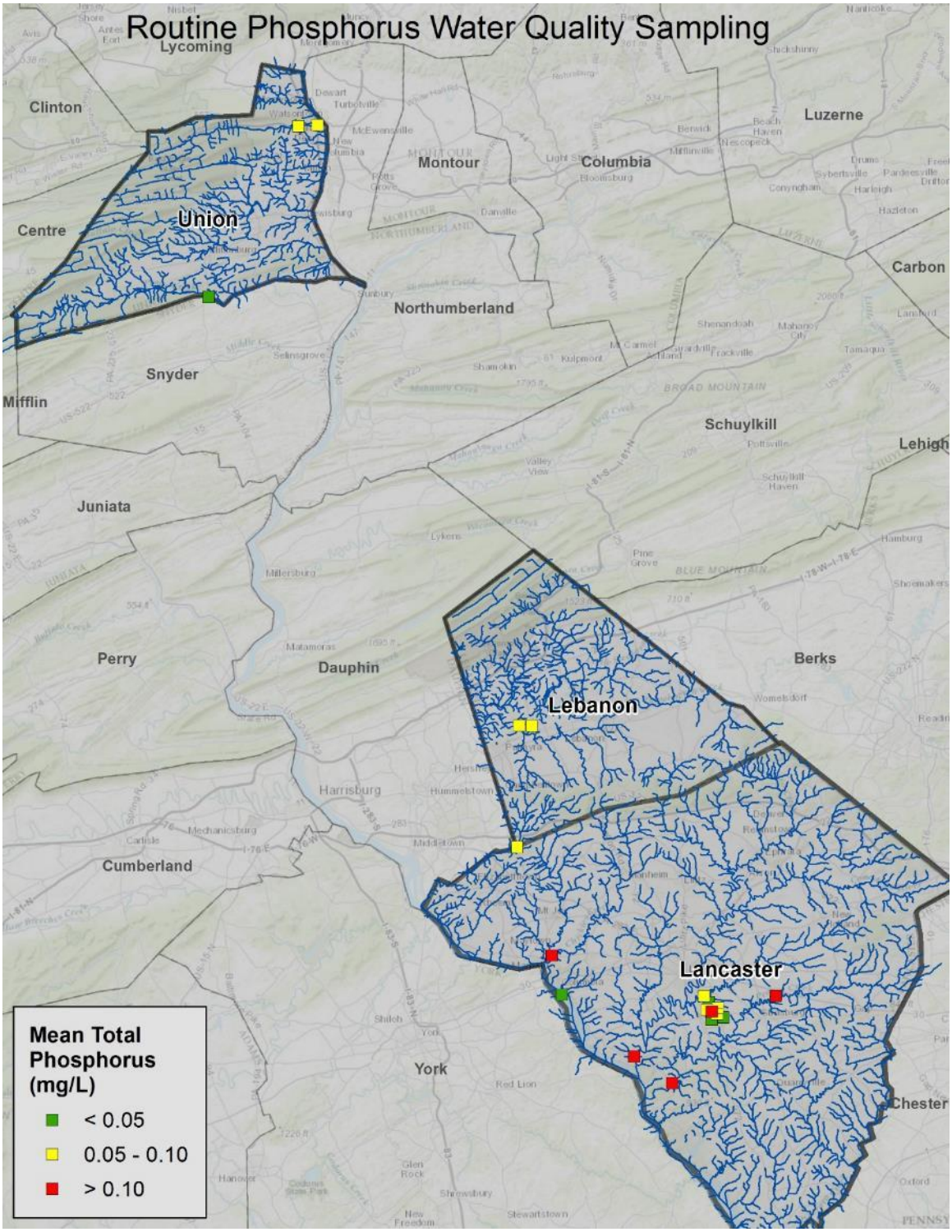


Figure 8: Total phosphorus sampling data from Pennsylvania DEP, 20112-2016. The mean values shown here only include routine sampling (no sampling from storm events). Virginia's threshold for "suboptimal" total phosphorus levels is 0.05 mg/L. There were no total phosphorus data for Franklin County. See Appendix B for more detail.



b. Impaired waterways

The nutrient pollution in these waterways contributes to widespread "impairments," which are documented in Pennsylvania DEP's annual water quality monitoring report.[122] The report categorizes impairments by both source (e.g., agriculture) and cause (e.g., nutrients, meaning nitrogen and phosphorus).[123] This means that stream segments can be impaired by agricultural sources of nitrogen and phosphorus, or by agricultural sources of other pollutants. One of the leading causes of impairments in Pennsylvania, for example, is siltation. Siltation is frequently caused by soil runoff from agricultural land.[124] Another common cause of impairments is pathogens, typically bacteria at levels that make recreational use of a waterway unsafe.[125] Many pathogen impairments are linked to agriculture, while others are coded as "unknown." The Pennsylvania DEP states that "[i]f there are several potential sources of bacteria in the watershed, the assessor lists the source as unknown until better information becomes available."[126] In other words, some of the "unknown" impairments invariably are associated with agriculture in addition to other sources. **Table 11** summarizes impairment data for the four counties, and **Figures 9 through 11** show impairment locations.

Table 11: Stream impairment summary[127]

	Franklin	Lancaster	Lebanon	Union	Four Counties	PA as a whole [128]
Miles assessed	2,655	2,553	969	772	6,979	84,372
Impaired by nutrients from agriculture (miles)	91	562	83	30	766	
Impaired by pathogens from agriculture (miles)	0	106	3	0	109	
Other agriculture-related impairments (miles)	183	364	182	74	804	
Total agriculture-related impairments (miles)	274	1,033	268	104	1,679	6,798
Agricultural impairments as fraction of miles assessed	10%	40%	27%	13%	24%	8%
Pathogens, source unknown (miles impaired)	899	798	304	6	1,992	

Figure 9: Water quality impairments in Lancaster and Lebanon Counties.[129]

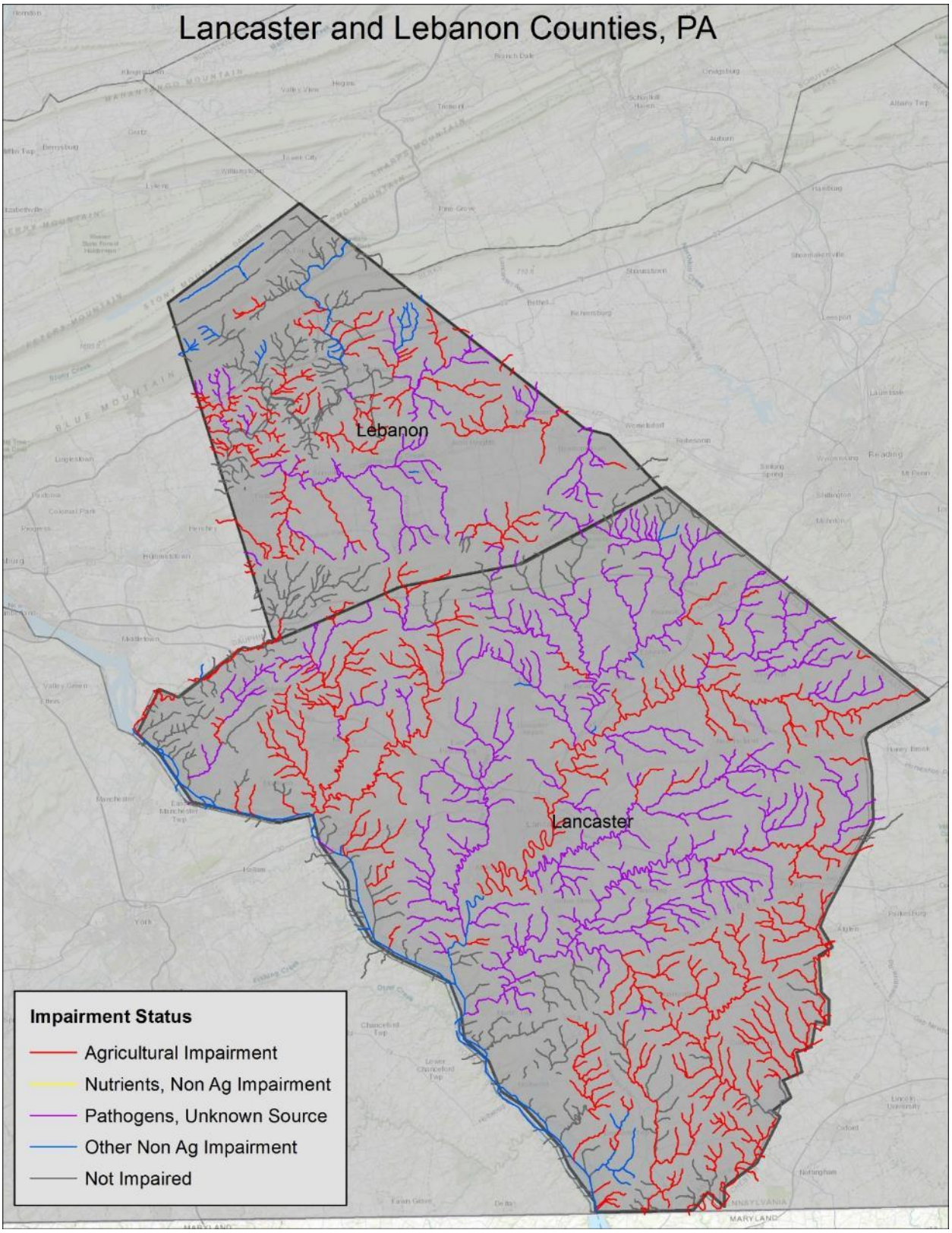


Figure 10: Water quality impairments in Franklin County.[130]

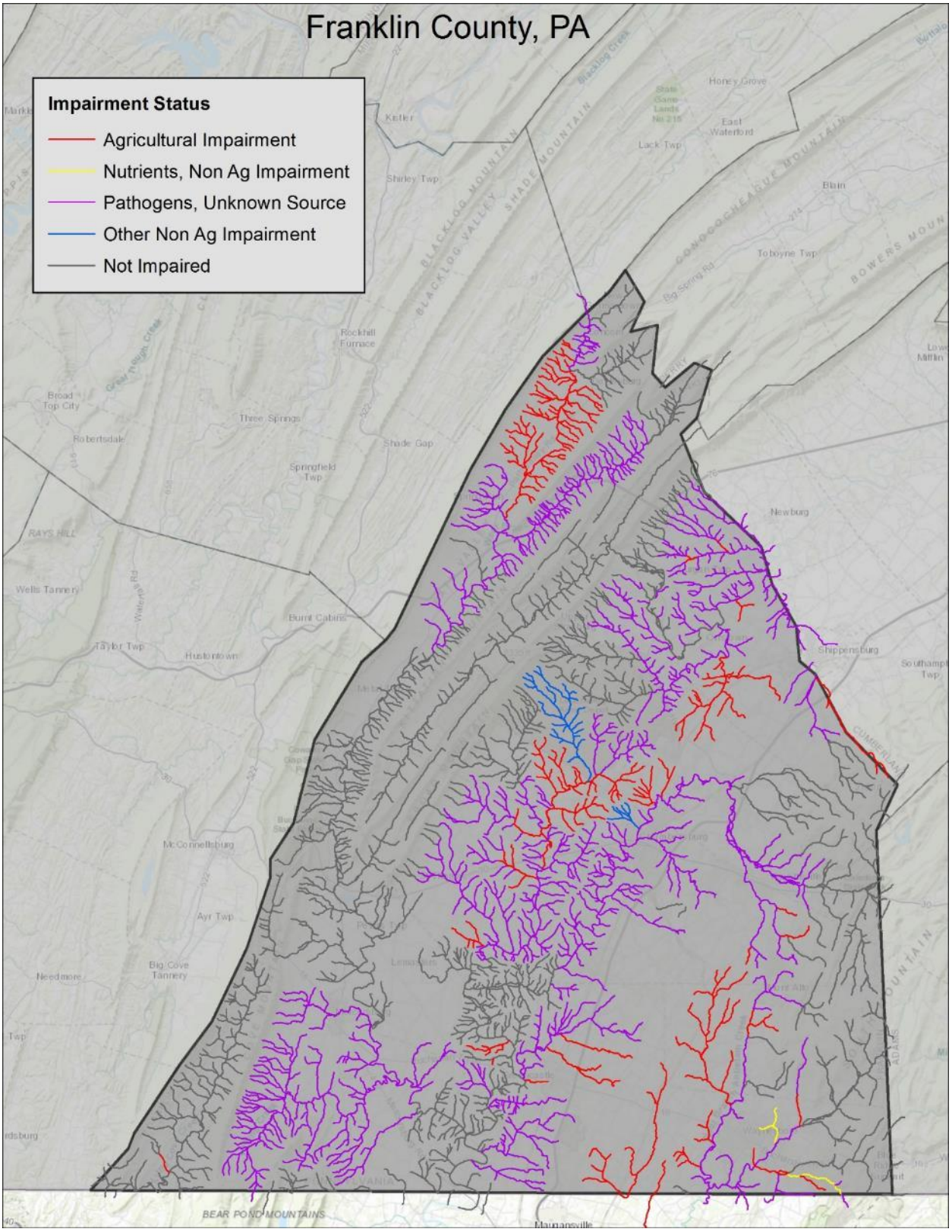
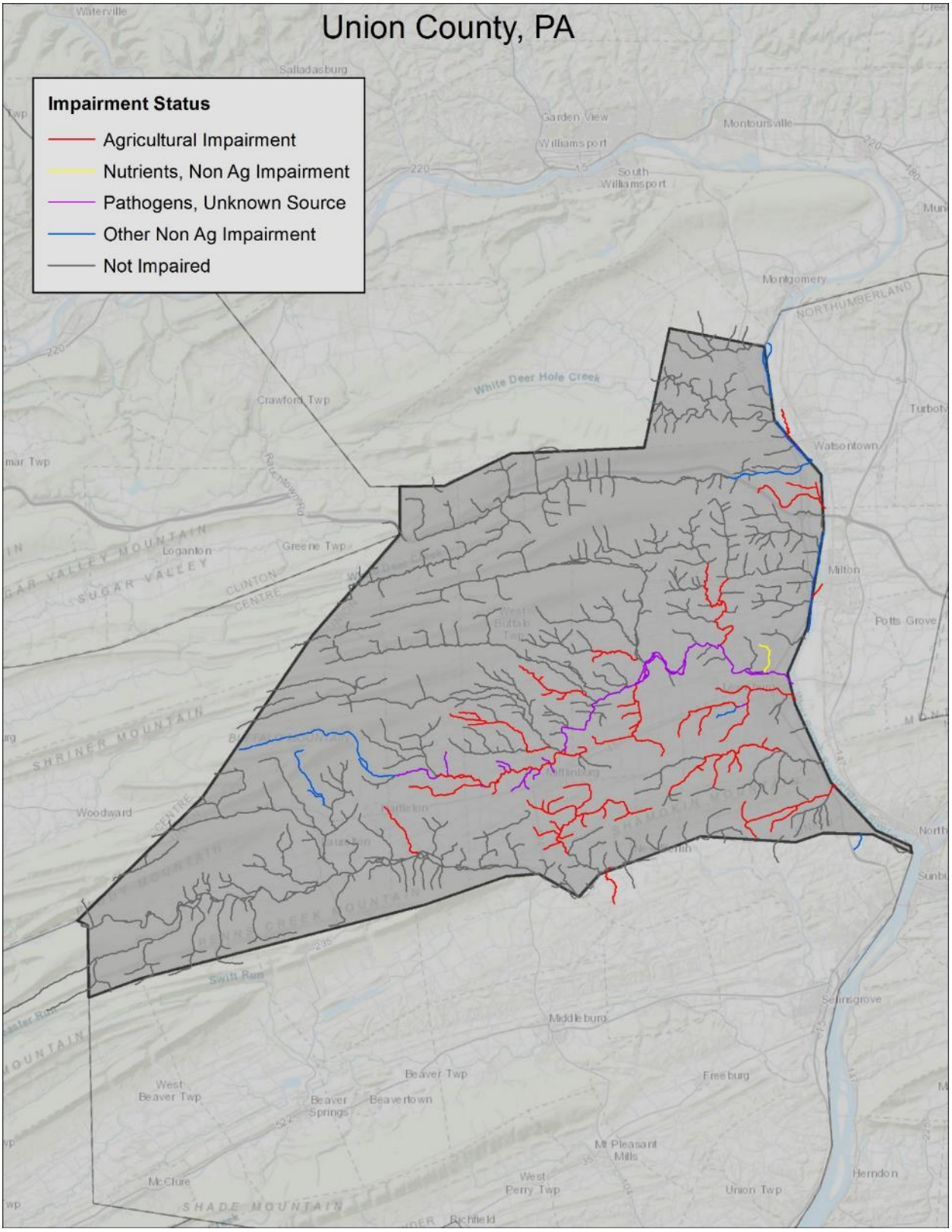


Figure 11: Water quality impairments in Union County.[131]



5. Discussion and Conclusions

Animal production in the four focus counties of Franklin, Lancaster, Lebanon, and Union reflects statewide patterns, but is much more intensive, with three times as many dairy cows per agricultural acre, and roughly six times as many chickens. In these four counties, the land-application of manure phosphorus has increased twice as fast as in the rest of the Commonwealth, while the land-application of manure nitrogen has increased four times as fast. As a result, the fraction of waterways impaired by agriculture is three times higher in these counties than it is elsewhere (see Table 10 above).

There simply isn't enough cropland in these counties to safely absorb this much waste. Most operations are only subject to the lenient and unenforceable recommendations found in Pennsylvania's Manure Management Manual. In fact, farmers who follow the Manual are encouraged to over-apply manure in order to meet crop nitrogen needs, based on optimistic estimates of crop yield, with no consideration of cropping history, soil nutrient levels, or phosphorus runoff risk. There is very little oversight of these operations' manure applications, and it is likely that many fields receive even more manure than the Manual would recommend.

Concentrated Animal Operations (CAOs) and Concentrated Animal Feeding Operations (CAFOs) are subject to more stringent Nutrient Management Plan requirements and water discharge permits, but again, given the flexibility in nutrient management planning regulations and the limited degree of compliance monitoring and enforcement, operators following NMPs may also be systematically over-applying manure to cropland. And once manure from CAOs and CAFOs is exported to neighboring farms, the level of care with which it is land-applied is significantly diminished and the Commonwealth has no effective mechanism to track the transfer.

As Penn State cautions, "[m]anure management needs to be more than just a plan to get rid of the stuff."[132] Unfortunately, the land-application of manure in the four focus counties looks more like waste disposal than fertilization. In order to prevent ongoing loss of nitrogen and phosphorus from cropland, the following changes should be made:

- The number of animals being packed into the four focus counties is unsustainable. Pennsylvania should eventually find a way to cap animal production at a more reasonable level, or at least more aggressively export manure out of the animal-dense counties.

- Manure should be applied more efficiently. Manure Management Plans (MMPs) are inadequate because they ignore soil nutrient content, crop history, and phosphorus runoff risk, and because they are largely voluntary. Nutrient Management Plans (NMPs) should be required for all farms that land-apply manure, particularly in counties with intensive animal production. This would have numerous benefits. For example, unlike MMPs, NMPs must be adjusted when actual yield does not match predicted yield. NMPs use the phosphorus index to minimize phosphorus runoff from high-risk fields and account for residual soil nitrogen from past crops.

- Even if NMP requirements are not extended to all farms, all manure applications should at the very least utilize the Phosphorus Index.

- Going beyond traditional nutrient management, manure applications should follow advanced nutrient management practices, such as those identified in section 3(j) above, in order to maximize the delivery of nutrients to growing crops and minimize nitrogen and phosphorus pollution.

- Pennsylvania should, after repealing the prohibition on stream fencing regulations, require stream fencing and other practices that keep livestock out of streams.

- Winter applications of manure should be restricted, as suggested by EPA,[133] or prohibited.

- Cost-share, market-based, and other voluntary programs to increase the use of Best Management Practices are not working.[134] Efficient manure application practices should be required, and these requirements should be enforced.

- Finally, while we believe that significant regulatory reform is sorely needed, we also agree with the EPA, and with the aspirations expressed in Pennsylvania's reboot strategy, regarding enhanced oversight and enforcement of the existing regulatory framework. As stated by the Pennsylvania DEP, "[i]nspection and verification activities related to agricultural and urban stormwater sources have been a missing piece in creating a culture of compliance with existing regulatory requirements… ."[135]

Pennsylvania's reboot strategy is a step in the right direction, and we hope the Commonwealth can follow through and take further, necessary measures to reign in the rampant over-application of manure to cropland. However, an effective strategy will have to recognize that Pennsylvania is currently lagging behind the required level of effort. It will also have to place special emphasis on agricultural hot spots within the state, including the four states analyzed in this report. At this point, the pollution impacts are so severe and immediate that incremental adjustments to Pennsylvania's regulatory framework will not be adequate. It is also important to note that many elements of the reboot strategy and EPA's recommendations will require additional resources. Pennsylvania DEP expects that the reboot strategy (which includes both agricultural and non-agricultural components) "could require a total of 40 additional positions and an annual General Fund budget increase of $7.3 million."[136] With the ongoing history of budget cuts affecting Pennsylvania DEP, it is hard to imagine where these additional resources will come from.[137] The reboot strategy includes some important goals, but in order to make a meaningful dent in the over-application of manure, the Commonwealth will have to do more, including the difficult work of comprehensive regulatory reform.

Appendix A: Detailed analysis of Chesapeake Bay Program Phase 6 Watershed Model Input Data

The Chesapeake Bay Program recently began posting a large quantity of data describing the inputs to its new, Phase 6 Watershed Model, the model used to estimate pollution loads and assess progress toward TMDL goals.[138] These data generally cover the 1984-2013 time period. The current version of the interface for accessing the input data provides "Beta 4" and "draft final" versions of the input data. All analyses presented below use "draft final" data. The interface has two levels. The first level is a set of five links, including Animal Data, Atmospheric Deposition Data, Soils and Plant Uptake Data, Nutrient Applications, and Septic Data. Each link brings up a series of maps or charts, shown as a series of tabs across the top of the interface. For example, the Animal Data link includes tabs with names like "Animal Dashboard," "Animal Map," Animal Unit per Acre," etc. Data can be downloaded from each tab. Footnotes to the data presented below name the link, followed by the tab. For example, Table A1 below is derived from "Nutrient Applications, Nutrients Applied Graph tab."

Table A1. 2013 Nitrogen Application Rate on Agricultural Land: Twenty Highest Counties in the Chesapeake Bay Watershed[139]

State	County	Nitrogen Application Rate (lb/acre)
MD	Somerset	177
PA	Lancaster	147
DE	Sussex	135
PA	Lebanon	124
VA	Rockingham	108
MD	Worcester	106
VA	Page	103
MD	Caroline	100
MD	Wicomico	97
DE	Kent	97
PA	Franklin	92
VA	Accomacl	89
DE	New Castle	87
WV	Hardy	87
PA	Berks	86
PA	Blair	85
PA	Cumberland	85
PA	York	83
PA	Union	81
PA	Chester	78

Table A2. 2013 Phosphorus Application Rate on Agricultural Land: Twenty Highest Counties in the Chesapeake Bay Watershed[140]

State	County	Phosphorus Application Rate (lb/acre)
MD	Somerset	54.5
PA	Lancaster	40.3
PA	Lebanon	34.8
DE	Sussex	32.3
VA	Page	31.7
VA	Rockingham	30.9
MD	Wicomico	29.7
WV	Hardy	26.3
VA	Amelia	23.8
MD	Worcester	23.8
PA	Union	21.9
MD	Caroline	21.7
PA	Snyder	20.9
PA	Dauphin	20.9
VA	Accomack	20.7
PA	Franklin	20.2
VA	Cumberland	19.6
DE	Kent	19.5
PA	Berks	19.0
PA	Schuylkill	18.2

Table A3: 2013 nitrogen and phosphorus application rates for the four focus counties and the rest of the Commonwealth. [141]

	Nitrogen		Phosphorus	
	Pounds per acre, Total	Pounds per acre, Agriculture	Pounds per acre, Total	Pounds per acre, Agriculture
Franklin	75	92	16	20
Lancaster	112	147	30	40
Lebanon	95	124	26	35
Union	66	81	18	22
Four focus counties	95	121	24	32
Other counties	44	59	9	12

Table A4: Changes in nitrogen application for the four focus counties and the rest of the Commonwealth.[142]

	30-year change, 1984-2013			10-year change, 2004-2013		
	Agricultural acres	Pounds	Pounds per acre	Agricultural acres	Pounds	Pounds per acre
Lancaster	-14%	+7%	+25%	-3%	+16%	+19%
Lebanon	-10%	+23%	+37%	-2%	+12%	+14%
Franklin	-3%	+15%	+19%	+3%	+9%	+6%
Union	-11%	+12%	+26%	0%	+13%	+13%
Four focus counties	-10%	+11%	+24%	-1%	+13%	+14%
Other counties	-11%	-2%	+9%	-3%	+4%	+6%

Table A5: Changes in phosphorus application for the four focus counties and the rest of the Commonwealth.[143]

	30-year trend, 1984-2013			10-year trend, 2004-2013		
	Agricultural acres	Pounds	Pounds per acre	Agricultural acres	Pounds	Pounds per acre
Lancaster	-14%	-10%	+5%	-3%	+9%	+12%
Lebanon	-10%	+13%	+26%	-2%	+4%	+6%
Franklin	-3%	-9%	-6%	+3%	+2%	-0.2%
Union	-11%	+5%	+17%	0%	+12%	+12%
Four focus counties	-10%	-6%	+4%	-1%	+7%	+8%
Other counties	-11%	-31%	-23%	-3%	-6%	-4%

Table A6: Sources of nitrogen and phosphorus applied to cropland in 2013[144]

	Source as % of total land-applied nitrogen		Source as % of total land-applied phosphorus	
	Fertilizer	Manure	Fertilizer	Manure
Lancaster	33%	67%	19%	81%
Lebanon	35%	65%	23%	77%
Franklin	56%	44%	39%	61%
Union	43%	57%	31%	76%
Four focus counties	39%	61%	24%	76%
Other four counties	72%	28%	58%	42%

Table A7: Manure nitrogen application trends for the four focus counties and the rest of the Commonwealth.[145]

	30-year trend, 1984-2013			10-year trend, 2004-2013		
	Agricultural acres	Pounds	Pounds per acre	Agricultural acres	Pounds	Pounds per acre
Lancaster	-14%	+14%	+32%	-3%	+14%	+17%
Lebanon	-10%	+61%	+79%	-2%	+7%	+9%
Franklin	-3%	+41%	+46%	+3%	+1%	-2%
Union	-11%	+93%	+26%	0%	+18%	+18%
Four focus counties	-10%	+26%	+40%	-1%	+11%	+11%
Other counties	-11%	-3%	+9%	-3%	-3%	-0.3%

Table A8: Manure phosphorus application trends for the four focus counties and the rest of the Commonwealth.[146]

	30-year trend, 1984-2013			10-year trend, 2004-2013		
	Agricultural acres	Pounds	Pounds per acre	Agricultural acres	Pounds	Pounds per acre
Lancaster	-14%	-1%	+15%	-3%	+15%	+18%
Lebanon	-10%	+58%	+76%	-2%	+6%	+8%
Franklin	-3%	+45%	+50%	+3%	+4%	+1%
Union	-11%	+120%	+146%	-0.1%	+25%	+25%
Four focus counties	-10%	+14%	+27%	-1%	+12%	+13%
Other counties	-1%	+1%	+13%	-3%	-4%	-1%

Table A9: Animals at Concentrated Animal Feeding Operations.[147]

	Livestock Animal Units (% of PA total)	Poultry Animal Units (% of PA total)
Lancaster	72,825 (30%)	159,974 (33%)
Lebanon	14,482 (6%)	128,373 (26%)
Franklin	21,584 (9%)	15,037 (3%)
Union	6,288 (3%)	2,095 (0.4%)
Four focus counties	115,179 (47%)	305,478 (63%)
Other Counties	130,723 (53%)	179,331 (37%)

Table A10: Animals production statistics over time.[148]

	Annual average (1984-86)	Annual average (2011-13)	Change
Four focus counties			
Beef	9,249	11,983	+30%
Dairy	165,205	190,918	+16%
Hogs and Pigs for breeding	45,410	48,641	+7%
Hogs for slaughter	420,874	811,042	+93%
Broilers*	62,615,233	90,132,454	+44%
Layers	12,695,865	15,009,221	+18%
Pullets	3,461,774	4,286,282	+24%
Turkeys*	1,164,522	1,979,921	+70%
Other counties			
Beef	79,697	80,397	1%
Dairy	387,204	284,409	-27%
Hogs and Pigs for breeding	48,742	50,787	4%
Hogs for slaughter	352,456	825,004	134%
Broilers*	44,511,305	80,887,825	82%
Layers	6,652,574	9,250,659	39%
Pullets	1,601,475	2,482,161	55%
Turkeys*	5,951,547	4,822,401	-19%

*Broiler and Turkey numbers represent birds sold per year; all other animal counts represent average inventory.

Table A11: Manure and litter production statistics over time (tons; see important caveats below*).

	Annual average (1984-86)	Annual average (2011-13)	Change
Four focus counties			
Livestock manure (tons)			
Beef	87,484	113,345	+30%
Dairy	3,256,197	3,762,994	+16%
Hogs for slaughter	727,001	1,400,963	+93%
Wet poultry litter (broilers) or wet, as-excreted manure (for other poultry) (tons)			
Broilers	64,979	113,709	+75%
Layers	440,229	520,445	+18%
Turkeys	33,771	57,418	+70%
Other counties			
Livestock manure (tons)			
Beef	753,859	760,480	+1%
Dairy	7,631,784	5,605,701	-27%
Hogs for slaughter	608,819	1,425,080	+134%
Wet poultry litter (broilers) or wet, as-excreted manure (for other poultry) (tons)			
Broilers	46,192	102,046	+121%
Layers	230,678	320,767	+39%
Turkeys	172,595	139,850	-19%

*Livestock and poultry manure estimates were derived using different methods and are not comparable. Livestock manure production was estimated using Chesapeake Bay Program Animal Unit numbers[149] and USDA manure production estimates for each animal type.[150] Poultry manure production was estimated using Bay Program animal production numbers (for broilers and turkeys) and animal inventory numbers (for layers).[151] However, unlike with livestock, we used poultry litter and manure production coefficients used by the Bay Program; the estimates used here are specific to Pennsylvania, change over time, and are expressed as dry litter per bird.[152]

These manure production estimates should not be added together for several reasons. First, as described above, they are not comparable. Second, this table only represent the subset of animal types for which we were able to estimate manure production. Total manure production would also include pullets, hogs and pigs for breeding, "other cattle," etc. Third, raw estimates of manure weight fail to account for the different nutrient content in each animal's manure. Finally, total manure production is more meaningful when considered on a per-acre basis. For comprehensive estimates of per-acre manure nitrogen and manure phosphorus applications, see Tables A7 and A8.

Table A12: Ammonia deposition in 2014

	Ammonia deposition (lb/acre)
Lancaster	9.4
Lebanon	8.1
Franklin	4.7
Union	4.2
Four focus counties combined	7.1
Other Counties	3.1

Appendix B: Pennsylvania water monitoring data, 2012-2016

The data summarized below were obtained from the Pennsylvania DEP Water Quality Network in May, 2017.[153] We isolated total nitrogen and total phosphorus data from the four focus counties, removed all blank results, removed all quality control results, and subdivided the remaining results into routine or stormwater sampling.

Table B1: Total Nitrogen, Pennsylvania DEP routine sampling[154]

County	Monitor	Latitude	Longitude	Date range		N	mean (mg/L)
Lancaster	21PA_WQX-WQN0201	40.0286	-76.5167	1/19/12	12/29/16	116	1.06
Lancaster	21PA_WQX-WQN0204	39.9056	-76.3281	1/19/12	12/20/16	58	7.22
Lancaster	21PA_WQX-WQN0206	40.0628	-76.5153	2/21/12	11/2/16	30	7.41
Lancaster	21PA_WQX-WQN0273	39.9389	-76.3869	1/19/12	12/29/16	114	6.48
Lancaster	21PA_WQX-WQN0278	40.195	-76.5675	1/31/12	12/13/16	58	2.19
Lancaster	21PA_WQX-WQN0280	39.9956	-76.2636	1/31/12	12/14/16	58	9.03
Lancaster	21PA_WQX-WQN0284	40.0092	-76.1622	11/20/12	12/14/16	49	8.04
Lebanon	21PA_WQX-WQN0285	40.3422	-76.5608	11/20/12	12/12/16	51	6.53
Union	21PA_WQX-WQN0229	40.8672	-77.0489	1/17/12	12/14/16	59	1.28
Union	21PA_WQX-WQN0461	41.0736	-76.9028	12/5/12	12/8/14	6	0.90

Table B2: Total Nitrogen, Pennsylvania DEP stormwater sampling[155]

County	Monitor	Latitude	Longitude	Date range		N	mean (mg/L)
Lancaster	21PA_WQX-WQN0201	40.0286	-76.5167	1/28/12	10/25/16	40	1.75
Lancaster	21PA_WQX-WQN0204	39.9056	-76.3281	1/28/12	9/30/16	38	5.96
Lancaster	21PA_WQX-WQN0273	39.9389	-76.3869	1/28/12	9/30/16	44	4.98
Lancaster	21PA_WQX-WQN0278	40.195	-76.5675	1/12/12	11/29/16	38	2.73
Lancaster	21PA_WQX-WQN0280	39.9956	-76.2636	1/12/12	9/29/16	35	4.31
Lancaster	21PA_WQX-WQN0284	40.0092	-76.1622	1/31/13	12/1/16	28	6.47
Lebanon	21PA_WQX-WQN0229	40.8672	-77.0489	1/28/12	9/30/16	31	1.62

Table B3: Total Phosphorus, routine Pennsylvania DEP and USGS sampling[156]

County	Monitor	Latitude	Longitude	Date range		N	Mean (mg/L)
Lancaster	21PA_WQX-WQN0201	40.0286	-76.5167	1/19/12	12/29/16	116	0.041
Lancaster	21PA_WQX-WQN0204	39.9056	-76.3281	1/19/12	12/20/16	58	0.150
Lancaster	21PA_WQX-WQN0206	40.0628	-76.5153	2/21/12	11/2/16	30	0.107
Lancaster	21PA_WQX-WQN0273	39.9389	-76.3869	1/19/12	12/29/16	114	0.174
Lancaster	21PA_WQX-WQN0278	40.1950	-76.5675	1/31/12	12/13/16	59	0.076
Lancaster	21PA_WQX-WQN0280	39.9956	-76.2636	1/31/12	12/14/16	59	0.039
Lancaster	21PA_WQX-WQN0284	40.0092	-76.1622	11/20/12	12/14/16	50	0.101
Lancaster	USGS-01575900	40.0629	-76.5155	2/21/12	11/2/16	30	0.105
Lancaster	USGS-015765159 AND 01576516	39.9915	-76.2609	9/17/12	12/14/16	24	0.038
Lancaster	USGS-015765166	39.9925	-76.2622	9/19/12	9/16/13	8	0.068
Lancaster	USGS-015765184 and 015765185	39.9912	-76.2640	9/19/12	12/14/16	18	0.046
Lancaster	USGS-015765188	39.9928	-76.2628	9/19/12	9/16/13	8	0.119
Lancaster	USGS-015765191	39.9933	-76.2622	9/17/12	9/16/13	8	0.058
Lancaster	USGS-015765193	39.9950	-76.2639	9/17/12	9/16/13	9	0.053
Lancaster	USGS-015765195	39.9959	-76.2640	1/12/12	12/14/16	65	0.076
Lancaster	USGS-01576767	40.0092	-76.1622	11/20/12	12/14/16	58	0.167
Lebanon	21PA_WQX-WQN0285	40.3422	-76.5608	11/20/12	12/12/16	51	0.096
Lebanon	USGS-01573160	40.3426	-76.5619	11/20/12	12/12/16	55	0.099
Union	21PA_WQX-WQN0229	40.8672	-77.0489	1/17/12	12/14/16	58	0.023
Union	21PA_WQX-WQN0461	41.0736	-76.9028	2/27/13	6/3/14	3	0.057
Union	USGS-01553150	41.0748	-76.8725	2/27/13	6/3/14	3	0.054

Table B4: Total Phosphorus, Pennsylvania DEP and USGS stormwater sampling[157]

County	Monitor	Latitude	Longitude	Date range		N	Mean (mg/L)
Lancaster	21PA_WQX-WQN0201	40.0286	-76.5167	1/28/12	10/25/16	40	0.150
Lancaster	21PA_WQX-WQN0204	39.9056	-76.3281	1/28/12	9/30/16	38	0.711
Lancaster	21PA_WQX-WQN0273	39.9389	-76.3869	1/28/12	9/30/16	44	0.445
Lancaster	21PA_WQX-WQN0278	40.1950	-76.5675	1/12/12	11/29/16	38	0.373
Lancaster	21PA_WQX-WQN0280	39.9956	-76.2636	1/12/12	9/29/16	35	0.272
Lancaster	21PA_WQX-WQN0284	40.0092	-76.1622	1/31/13	12/1/16	28	0.633
Lancaster	USGS-01576000	40.0545	-76.5308	5/18/14	2/29/16	17	0.190
Lancaster	USGS-01576516	39.9915	-76.2609	11/6/14	9/30/15	6	0.477
Lancaster	USGS-015765185	39.9912	-76.2640	11/6/14	9/30/15	9	0.156
Lancaster	USGS-015765195	39.9959	-76.2640	1/31/13	12/29/15	26	0.257
Lancaster	USGS-01576767	40.0092	-76.1622	1/31/13	10/29/15	19	0.616
Lancaster	USGS-01576980	39.8279	-76.3333	5/20/14	2/29/16	18	0.138
Lebanon	21PA_WQX-WQN0285	40.3422	-76.5608	12/21/12	9/29/16	29	0.204
Lebanon	USGS-01573160	40.3426	-76.5619	12/21/12	12/2/15	23	0.217
Lebanon	USGS-01573670	40.2406	-76.5122	5/15/12	5/15/12	1	0.110
Lebanon	USGS-01573680	40.2308	-76.5581	5/15/12	5/15/12	1	0.600
Lebanon	USGS-01573690	40.2161	-76.5589	5/15/12	5/15/12	1	0.400
Union	21PA_WQX-WQN0229	40.8672	-77.0489	1/28/12	9/30/16	31	0.086

Table B5: Total Phosphorus, Susquehanna River Basin Commission sampling in Lancaster County.[158] Highlighted means exceed Virginia's "suboptimal" threshold of 0.05 mg/L.

Monitor	Latitude	Longitude	Date range		N	Mean (mg/L)
42SRBCWQ_WQX-SUSQ018.0-3976	39.7500	-76.2560	4/24/12	8/18/14	4	0.042
42SRBCWQ_WQX-SUSQ018.1-3976	39.7540	-76.2470	4/24/12	8/18/14	4	0.044
42SRBCWQ_WQX-SUSQ018.2-3976	39.7590	-76.2360	4/24/12	8/18/14	4	0.046
42SRBCWQ_WQX-SUSQ022.0-3976	39.7914	-76.2911	4/24/12	8/18/14	5	0.053
42SRBCWQ_WQX-SUSQ022.1-3976	39.7978	-76.2953	4/24/12	8/18/14	5	0.044
42SRBCWQ_WQX-SUSQ022.2-3976	39.8006	-76.2900	4/24/12	8/18/14	4	0.057
42SRBCWQ_WQX-SUSQ026.0-3976	39.8392	-76.3506	4/25/12	8/19/14	5	0.032
42SRBCWQ_WQX-SUSQ026.1-3976	39.8403	-76.3483	4/25/12	8/19/14	5	0.038
42SRBCWQ_WQX-SUSQ026.2-3976	39.8414	-76.3461	4/25/12	8/19/14	5	0.049
42SRBCWQ_WQX-SUSQ030.0-3976	39.8889	-76.3794	4/25/12	8/19/14	5	0.047
42SRBCWQ_WQX-SUSQ030.1-3976	39.8894	-76.3736	4/25/12	8/19/14	5	0.049
42SRBCWQ_WQX-SUSQ030.2-3976	39.8900	-76.3669	4/25/12	8/19/14	5	0.064
42SRBCWQ_WQX-SUSQ034.0-3976	39.9253	-76.4206	4/25/12	8/20/14	4	0.050
42SRBCWQ_WQX-SUSQ034.1-3976	39.9289	-76.4169	4/25/12	8/20/14	4	0.053
42SRBCWQ_WQX-SUSQ034.2-3976	39.9319	-76.4136	4/25/12	8/20/14	4	0.046
42SRBCWQ_WQX-SUSQ038.1-3976	39.9631	-76.4864	4/25/12	8/20/14	6	0.046
42SRBCWQ_WQX-SUSQ038.2-3976	39.9669	-76.4719	4/25/12	8/20/14	4	0.031
42SRBCWQ_WQX-SUSQ038.3-3976	39.9700	-76.4597	4/25/12	8/20/14	4	0.050
42SRBCWQ_WQX-SUSQ044.0-4076	40.0283	-76.5264	4/25/12	8/20/14	6	0.060
42SRBCWQ_WQX-SUSQ044.1-4076	40.0306	-76.5192	4/25/12	8/20/14	5	0.041
42SRBCWQ_WQX-SUSQ044.2-4076	40.0314	-76.5103	4/25/12	8/20/14	5	0.049
42SRBCWQ_WQX-SUSQ044.5-4076	40.0280	-76.5192	11/26/12	10/28/14	2	0.038

Monitor	Latitude	Longitude	Date range		N	Mean (mg/L)
42SRBCWQ_WQX-SUSQ047.0-0000	40.0520	-76.5962	6/18/14	8/25/14	2	0.088
42SRBCWQ_WQX-SUSQ047.1-00000	40.0538	-76.5948	6/18/14	8/25/14	2	0.041
42SRBCWQ_WQX-SUSQ047.2-00000	40.0559	-76.5943	6/18/14	8/25/14	2	0.056
42SRBCWQ_WQX-SUSQ053.0-00000	40.0831	-76.6780	6/19/14	8/21/14	2	0.028
42SRBCWQ_WQX-SUSQ053.1-00000	40.0861	-76.6746	6/19/14	8/21/14	4	0.033

Notes

[1] Chesapeake Bay Program, Restoration, http://www.chesapeakebay.net/track/restoration (see "Reducing Nitrogen Pollution" and "Reducing Phosphorus Pollution" links).

[2] See, e.g., U.S. EPA, Chesapeake Bay Progress: Wastewater Pollution Reduction Leads the Way (June, 2016), http://www.chesapeakebay.net/track/health/bayhealth.

[3] See, e.g., Chesapeake Bay Program, Health, http://www.chesapeakebay.net/track/health.

[4] All data come from a spreadsheet found on the Chesapeake Bay Program "Chesapeake Progress" websites (see, e.g., http://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans). Last accessed June 30, 2017.

[5] Id.

[6] Id.

[7] Id.

[8] Chesapeake Bay Program, Graphical interface to the Phase 6 Watershed Model Inputs, https://mpa.chesapeakebay.net/Phase6DataVisualization.html (hereinafter "Phase 6 Model Inputs").

[9] Throughout this report, with the exception of manure transfer statistics, references to "Pennsylvania" should be read as "parts of Pennsylvania within the Chesapeake Bay Watershed."

[10] Phase 6 Model Inputs, Nutrient Applications, Nutrient Applied Graph tab.

[11] Id.

[12] Id.

[13] Id.

[14] Id.

[15] Phase 6 Model Inputs, Nutrient Applications, Nutrient Source tab.

[16] Calculated from previous rows in this table.

[17] Id.

[18] Phase 6 Model Inputs, Atmospheric Deposition Data, Atmospheric Deposition Map tab.

[19] Phase 6 Model Inputs, Nutrient Applications, Nutrients Applied Graph tab.

[20] Id.

[21] Phase 6 Model Inputs, Nutrient Applications, Nutrient Source tab.

[22] Calculated from previous rows in this table.

[23] Id.

[24] Phase 6 Model Inputs, Animal Data, Animal Units tab. This table shows animal data for "permitted feeding space" (i.e., CAFOs).

[25] Id.

[26] Phase 6 Model Inputs, Nutrient Applications, Nutrients Applied Graph tab.

[27] Id.

[28] Phase 6 Model Inputs, Nutrient Applications, Nutrient Source tab.

[29] Id.

[30] Id., Animal Data, Animal Units tab. The Bay Model currently assigns animal production to either "permitted feeding space" (i.e., CAFOs) or "non-permitted feeding space."

[31] Id. In the four focus counties, CAFOs account for 36 percent of animal production.

[32] Pennsylvania DEP, eFACTS database, http://www.ahs.dep.pa.gov/eFACTSWeb/criteria_auth.aspx. We searched for authorization type "Concentrated Animal Feeding Operations indiv NPDES Pmt" by County. Search results cover the 1999-2017 time period. Over that time period, 248 facilities applied for "new" CAFO permits; 100 of these were in the four focus counties.

[33] Phase 6 Model Inputs, Animal Data, Animal Units tab. The numbers of broilers and turkeys appear to be annual production estimates (i.e., the number of birds sold each year), while the numbers for other animals reflect the estimated annual inventory (i.e., number of animals on farms at any given time).

[34] Manure transport data were obtained from Pennsylvania DEP in the form of a spreadsheet on March 7, 2017, in response to a Right-to-Know request.

[35] Id.

[36] We assume that most of these transfers are to farms that straddle county lines. For example, a 2015 transfer of 1,470 tons of chicken litter went from Union County to Union and Northumberland Counties.

[37] Here we are including transfers to multiple destinations including the county of origin as transfers to the county of origin.

[38] Phase 6 Model Inputs, Soils and Plant Uptake Data, Plant Nutrient Uptake Tab.

[39] U.S. EPA, 2014 National Emissions Inventory (NEI) Data, https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data (accessed Nov. 7, 2016).

[40] Phase 6 Model Inputs, Atmospheric Deposition Data, Atmospheric Deposition Map.

[41] Id.

[42] U.S. EPA, Development of Emissions Estimating Methodologies for Broiler Operations at 4-10 (Draft) (Feb. 2012).

[43] E.F. Wheeler et al., Ammonia Emissions from Twelve U.S. Broiler Chicken Houses, *Agricultural and Biosystems Engineering Publications, Paper 151* (2006). Wheeler et al. used ammonia emissions data to derive a daily emissions model – 0.031 grams of ammonia per bird per day for every day of bird age – that we applied to the flock history of barn H10 in EPA's emissions monitoring study.

[44] The EPA National Emissions Inventory assumes that emissions from broiler barns are equal to 0.22 pounds per broiler per year. U.S. EPA, NEI technical documentation, Table 3-29 (Aug. 2015), https://www.epa.gov/sites/production/files/2015-10/documents/nei2011v2_tsd_14aug2015.pdf; U.S. EPA, NEI technical documentation, Table 3-29 (Aug. 2015), https://www.epa.gov/sites/production/files/2015-10/documents/nei2011v2_tsd_14aug2015.pdf.

[45] 25 Pa. Code § 83.201.

[46] Animal Equivalent Units, or AEUs, are defined as "One thousand pounds live weight of livestock or poultry animals, on an annualized basis, regardless of the actual number of individual animals comprising the unit." Animal Units (AUs) are defined as "One thousand pounds live weight of livestock or poultry animals, regardless of the actual number of individual animals comprising the unit." One thousand pounds live weight of livestock or poultry animals, regardless of the actual number of individual animals comprising the unit. 25 Pa. Code § 83.201.

[47] DOUGLAS BEEGLE, PENNSTATE EXTENSION, NUTRIENT MANAGEMENT LEGISLATION IN PENNSYLVANIA: A SUMMARY IF THE 2006 REGULATIONS 1 (2010), http://extension.psu.edu/plants/nutrient-management/act-38/nutrient-management-legislation-in-pennsylvania-a-summary-of-the-2006-regulations/extension_publication_file.

[48] For example, any operation that land-applies manure from a CAO or CAFO, either directly or through a broker, must adhere to certain setbacks from surface water. 25 Pa. Code § 91.36(b).

[49] Id; Pennsylvania DEP, Land Application of Manure, A supplement to Manure Management for Environmental Protection, Manure Management Plan Guidance 361-0300-002 (Oct. 29, 2011) (hereinafter "Manure Management Manual").

[50] 3 Pa.C.S.A., Pt. I, Ch. 5; 25 Pa. Code § 83, Subchapter D.

[51] 3 Pa.C.S.A. § 506(b).

[52] 3 Pa. Cons. Stat. §§ 506(c)-(e). The SCC is a 14-member commission under the joint authority of the Department of Environmental Protection and the Department of Agriculture. CCDs are county-level government units designed to carry out natural resource management programs. See, e.g., Pennsylvania Association of Conservation Districts, Inc., Conservation Districts brochure, https://pacd.org/wp-content/uploads/2009/06/FINALWebReadyPACDVersion.pdf.

[53] 25 Pa. Code § 83.291.

[54] Id.

[55] 25 Pa. Code § 83.292.

[56] Id.

[57] 25 Pa. Code § 83.293.

[58] 25 Pa. Code § 83.293.

[59] Id.

[60] Id.

[61] Id.

[62] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 38 (Feb. 2015).

[63] 25 Pa. Code § 92a.2. The state law definition also includes anything otherwise defined as a "large CAFO" under federal law, 40 C.F.R. § 122.23(b)(4).

[64] 25 Pa. Code § 92a.29(e).

[65] Penn State, The Pennsylvania Phosphorus Index Version 2 (2007).

[66] Id.

[67] 25 Pa. Code § 102.4

[68] 25 Pa. Code § 83.301.

[69] 25 Pa. Code § 83.343.

[70] See, e.g., U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 58 (Feb. 2015) ("Commerically hauled manure must be applied according to an NMP or MMP"); Pennsylvania Department of Agriculture, Commercial Manure Hauler & Broker Certification Workbook: Manure Hauler Level 2 at 7 (2015) (stating that "[i]f a farm is not a CAO or CAFO then manure must be applied according to the DEP MMP," but also suggesting that all exported CAO or CAFO manure must be land-applied following a Nutrient Balance Sheet).

[71] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 57 (Feb. 2015).

[72] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 48 (Feb. 2015).

[73] For an overview of stream exclusion, see Chesapeake Bay Commission, Healthy Livestock, Healthy Streams: Policy Actions to Promote Livestock Stream Exclusion.

[74] 35 Pa. Stat. Ann. § 691.702

[75] See Pennsylvania House Bill 1053, introduced April 3, 2017 (An Act amending the act of December 19, 1974 (P.L.973, No.319), known as the Pennsylvania Farmland and Forest Land Assessment Act of 1974, further providing for definitions and for applications for preferential assessments; and making related repeals); Pennsylvania House Bill 1060, introduced April 3, 2017 (An Act amending the act of June 22, 1937 (P.L.1987, No.394), known as The Clean Streams Law, in scope and purpose, repealing provisions relating to fences along streams).

[76] Chesapeake Bay Program, Chesapeake Progress, 2017 and 2025 Watershed Implementation Plans (WIPs), Best Management Plan database, available at http://www.chesapeakeprogress.com/files/SummaryBmps_2017-06-01.xlsx.

[77] Id.

[78] See, e.g., 3 Del. Admin. Code 1201-6.2.3 (prohibiting fertilizer applications between Dec. 7 and Feb. 15 for operations that are not required to have nutrient management plans); Maryland Nutrient Management Manual Section 1.D.III.D, available at http://mda.maryland.gov/resource_conservation/Pages/nm_manual.aspx (generally prohibiting fertilizer applications between Dec. 15 and Feb. 28).

[79] Manure Management Manual, supra note 49 at 8; 25 Pa. Code § 83.294(g).

[80] Id. at 8.

[81] Environmental Protection Agency, EPA Expectations for Pennsylvania's Phase III Watershed Implementation Plan, at 3 (Apr. 27, 2017) https://www.epa.gov/sites/production/files/2017-05/documents/final_pennsylvania_phase_iii_wip_expectations_4_27_17_508.pdf; PENNSYLVANIA DEPARTMENT OF

ENVIRONMENTAL PROTECTION, A DEP STRATEGY TO ENHANCE PENNSYLVANIA'S CHESAPEAKE BAY RESTORATION PROJECT, 27, http://files.dep.state.pa.us/Water/ChesapeakeBayOffice/DEP%20Chesapeake%20Bay%20Restoration%20Strategy%20012116.pdf

[82] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 48 (Feb. 2015).

[83] 25 Pa. Code § 83.342.

[84] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 40-41 (Feb. 2015).

[85] Id. at 47.

[86] Id. at 48.

[87] Id. at 47.

[88] U.S. EPA, Pennsylvania Animal Agriculture Program Assessment at 30 (Feb. 2015).

[89] Id. at 31.

[90] Id. at 32.

[91] Ad Crable, *$28 million headed to southcentral Pennsylvania farmers for pollution control*, Lancaster Online, Oct. 5, 2016, http://lancasteronline.com/news/local/million-headed-to-southcentral-pennsylvania-farmers-for-pollution-control/article_4c781686-8a68-11e6-bd28-176d146bba91.html.

[92] Pennsylvania DEP, Wolf Administration Announces Successful First Year for Expanded Agricultural Inspections in Chesapeake Bay Watershed (Press Release, Aug. 16, 2017), http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21272&typeid=1. See also Pennsylvania DEP, Chesapeake Bay Agricultural Inspection Program, September 1, 2016 through March 31, 2017, http://files.dep.state.pa.us/Water/BPNPSM/AgriculturalOperations/AgriculturalCompliance/CBAIP_QuarterlyReport_March17.pdf (showing that 64 percent of farms required to have MMPs have MMPs that meet state planning requirements, and 59 percent of farms have erosion and sediment control plans that meet state requirements).

[93] Id. at 26-29.

[94] Id. at 29.

[95] Environmental Protection Agency, EPA Evaluation of Pennsylvania's 2014-2015 and 2016-2017 Milestones 1 (2016), https://www.epa.gov/sites/production/files/2016-06/documents/pa_2014-2015_-_2016-2017_milestone_eval_06-17-16.pdf; Environmental Protection Agency, EPA Expectations for Pennsylvania's Phase III Watershed Implementation Plan 1 (Apr. 27, 2017) https://www.epa.gov/sites/production/files/2017-05/documents/final_pennsylvania_phase_iii_wip_expectations_4_27_17_508.pdf.

[96] PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION, A DEP STRATEGY TO ENHANCE PENNSYLVANIA'S CHESAPEAKE BAY RESTORATION PROJECT 2 (2016), http://files.dep.state.pa.us/Water/ChesapeakeBayOffice/DEP%20Chesapeake%20Bay%20Restoration%20Strategy%20012116.pdf.

[97] *See, e,g http://www.pennlive.com/politics/index.ssf/2017/02/environment_budget_cuts_unstai.html* (Feb. 21, 2017) (documenting the 2002 budget total and current budget proposal); http://www.lehighvalleylive.com/news/index.ssf/2017/06/house_senate_send_pennsylvania.html (June 30, 2017) (confirming the $148 million budget proposal).

[98] Manure Management Manual, supra note 49, at 10.

[99] Penn State Extension, Agronomy Facts 12: Nitrogen Fertilization of Corn (2003).

[100] Chesapeake Bay Program Agricultural Modeling Subcommittee to the Poultry Subcommittee and Agriculture Workgroup, Recommendations to Estimate Poultry Nutrient Production in the Phase 6 Watershed Model (Mar. 2015).

[101] Manure Management Manual, supra note 49, Appendix 1, page 13.

[102] Penn State Extension, Agronomy Facts 12: Nitrogen Fertilization of Corn at 2 (2003).

[103] Penn State Extension, Agronomy Facts 13: Managing Phosphorus for Crop Production at 3 (2002). This source states that a bushel of corn removes 0.4 pounds of phosphoric acid (P_2O_5) from the soil. A pound of P_2O_5 contains 0.44 pounds of phosphorus. A bushel of corn therefore removes 0.17 pounds of phosphorus from the soil.

[104] Id. at 4.

[105] Manure Management Manual, supranote 49, Appendix 1, page 13.

[106] Penn State Extension, Agronomy Facts 12: Nitrogen Fertilization of Corn at 2 (2003); Penn State Extension, Agronomy Facts 13: Managing Phosphorus for Crop Production at 3 (2002). This source states that a bushel of corn removes 0.4 pounds of phosphoric acid (P_2O_5) from the soil. A pound of P_2O_5 contains 0.44 pounds of phosphorus. A bushel of corn therefore removes 0.17 pounds of phosphorus from the soil. See also Virginia Cooperative Extension, Nitrogen and Phosphorus Fertilization of Corn, Publication 424-027, at 3 (2009) ("Research has shown that when efficiently applied, total N rates of 1.0 to 1.25 lb N per bushel of yield potentially are adequate to optimize yields."); Commonwealth of Virginia, Virginia Nutrient Management Standards and Criteria at 60 (Rev. July 2014) (showing that corn grain needs between 0 and 140 pounds of P_2O_5 per acre, or between 0 and 61 pounds of phosphorus, depending on soil productivity and soil phosphorus content).

[107] Id. at 5.

[108] Commonwealth of Virginia, Virginia Nutrient Management Standards and Criteria at 41, 60-108 (Rev. July 2014). This refers to a soil concentration of 127 parts per million using the Mehlich III procedure. The only crop for which phosphorus applications are recommended at high soil phosphorus levels is tobacco.

[109] Penn State Extension, Agronomy Facts 13: Managing Phosphorus for Crop Production at 4 (2002)

[110] Penn State Extension, Agronomy Facts 12: Nitrogen Fertilization of Corn at 4 (2003).

[111] Id.

[112] Id. at 5.

[113] Id.

[114] Id.

[115] Id.

[116] Chesapeake Bay Program, Nutrient Management Practices for Use in Phase 6.0 of the Chesapeake Bay Program Watershed Model (Nov. 2016).

[117] Virginia Department of Environmental Quality. Final 2014 305(b)/303(d) Water Quality Assessment Integrated Report, Chapter 4.4, Freshwater Probabilistic Monitoring Results, available at:

http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityAssessments/IntegratedReport/2014/ir14_Ch4.4_FPM_Assessment.pdf.

[118] See, e.g., U.S. EPA, State Progress Toward Developing Numeric Nutrient Water Quality Criteria for Nitrogen and Phosphorus, https://www.epa.gov/nutrient-policy-data/state-progress-toward-developing-numeric-nutrient-water-quality-criteria. To provide just a few examples from this database, Florida has regional nitrogen criteria for rivers and streams that range from 0.67 to 1.87 mg/L. Local criteria for total nitrogen in Arizona and California average 1.2 and 1.5 mg/L, respectively. The phosphorus standard for New Jersey rivers and streams is 0.1 mg/L. The average phosphorus standard for Vermont is 0.01 mg/L. The average of 61 local phosphorus standards in California is 0.05 mg/L.

[119] U.S. Geological Survey, Water-Quality Loads and Trends at Nontidal Monitoring Stations in the Chesapeake Bay Watershed, https://cbrim.er.usgs.gov/maps.html.

[120] Id.

[121] Id.

[122] Pennsylvania DEP, Draft 2016 Pennsylvania Integrated Water Quality Monitoring and Assessment Report, Clean Water Act Section 305(b) Report and 303(d) List (2016), available at http://www.dep.pa.gov/Business/Water/CleanWater/WaterQuality/Integrated%20Water%20Quality%20Report-2016/Pages/default.aspx.

[123] Pennsylvania DEP, Draft 2016 Pennsylvania Integrated Water Quality Monitoring and Assessment Report, Clean Water Act Section 305(b) Report and 303(d) List, Tables 3 and 4 (2016) http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-113834/2016_Draft_Pennsylvania_Integrated_Water_Quality_Monitoring_and_Assessment_Report_Updated_07-28-2016.pdf (hereinafter "Integrated Report").

[124] See, e.g., id. at 47 ("Agricultural impairments are generally caused by nutrients and siltation associated with surface runoff, groundwater input, and unrestricted access of livestock to streams.").

[125] Id.

[126] Id.

[127] Pennsylvania DEP Integrated Report data were obtained through Pennsylvania Spatial Data Access in July, 2017. http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=887 (attaining) and http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=888 (non-attaining).

[128] Integrated Report, supra note 123 at 1 and 45.

[129] Pennsylvania DEP Integrated Report data were obtained through Pennsylvania Spatial Data Access in July, 2017. http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=887 (attaining) and http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=888 (non-attaining).

[130] Id.

[131] Id.

[132] Penn State Extension, Agronomy Facts 12: Nitrogen Fertilization of Corn at 4 (2003).

[133] Environmental Protection Agency, EPA Expectations for Pennsylvania's Phase III Watershed Implementation Plan, at 3 (Apr. 27, 2017) https://www.epa.gov/sites/production/files/2017-05/documents/final_pennsylvania_phase_iii_wip_expectations_4_27_17_508.pdf.

[134] See, e.g., PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION, A DEP STRATEGY TO ENHANCE PENNSYLVANIA'S CHESAPEAKE BAY RESTORATION PROJECT, 1 (2016), http://files.dep.state.pa.us/Water/ChesapeakeBayOffice/DEP%20Chesapeake%20Bay%20Restoration%20Strategy%20012116.pdf ("[I]n FFY 2014, $146.6 million (combined state and Federal funding) was spent on programs to address nitrogen, phosphorus and sediment reduction statewide. $127.6 million, or 87 percent, was used for BMP deployment. The average cost-share on BMP installation is 75 percent … . Yet we still are not achieving our targeted reduction goals.").

[135] Id.

[136] Id. at 2.

[137] See, e.g., EPA Expectations for Pennsylvania's Phase III Watershed Implementation Plan, supra note 127, at 4 (EPA expects "a significant increase in resources focused on implementation of priority agricultural conservation practices"); supra note 94 (regarding Pennsylvania DEP budget cuts).

[138] Chesapeake Bay Program, Graphical interface to the Phase 6 Watershed Model Inputs, https://mpa.chesapeakebay.net/Phase6DataVisualization.html.

[139] Nutrient Applications, Nutrients Applied Graph tab.

[140] Id.

[141] Id.

[142] Nutrient Applications, Nutrients Applied Graph tab. Percent change was calculated as the difference between the average rates for the first three years of the stated time period and the last three years.

[143] Id.

[144] Nutrient Applications, Nutrient Source tab. These percentages exclude the nutrients directly deposited by grazing animals on pasture, which account for 10-20 percent of total nutrient inputs on agricultural land in Pennsylvania. Percentages do include biosolids, but biosolids typically make up much less than 1 percent of total land applications, so the combined total of manure and fertilizer is close to 100 percent of cropland applications.

[145] Nutrient Applications, Nutrient Source tab. Percent change was calculated as the difference between the average rate for the first three years of the stated time period and the last three years.

[146] Nutrient Applications, Nutrient Source tab. Percent change was calculated as the difference between the average rate for the first three years of the stated time period and the last three years.

[147] Animal Data, Animal Units tab. This table shows animal data for "permitted feeding space" (i.e., CAFOs).

[148] Animal Data, Animal Units tab.

[149] Id.

[150] U.S. Department of Agriculture, Animal Manure Management, RCA Issue Brief #7 (Dec. 1995), https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211.

[151] Animal Data, Animal Units tab.

[152] Chesapeake Bay Program Agricultural Modeling Subcommittee to the Poultry Subcommittee and Agriculture Workgroup, Recommendations to Estimate Poultry Nutrient Production in the Phase 6 Watershed Model (Mar. 2015).

[153] PA DEP, Water Quality Network, http://www.dep.pa.gov/Business/Water/CleanWater/WaterQuality/Pages/Water-Quality-Network.aspx.

[154] The average result for monitor 21PA_WQX-WQN0461 includes four "ambient" samples collected between 12/5/12 and 12/8/14 and two "routine" samples collected between 2/27/13 and 9/2/14.

[155] Stormwater averages include data with the Method Types "Routine, Storm-Impacted" and "Stormwater."

[156] Averages include data (1) with a Hydrologic Event code of "Routine" and (2) with a blank Hydrologic Event code and a Method Type of "Ambient Sampling" or "Routine Sampling." The USGS-01576516 average is a mean of data from USGS-01576516 (10/7/2014 - 12/14/2016, 16 results) and a monitor identified as USGS-015765159, which appears to be located in the same place and was monitored from 9/17/2012-9/17/2013 (8 results). The USGS-015765185 average is a mean of data from USGS-015765185 (10/7/2014 - 12/14/2016, 10 results) and a monitor identified as USGS-015765184, which appears to be located in the same place and was monitored from 9/19/2012-9/17/2013 (8 results). The 21PA_WQX-WQN0461 average is a mean of two "ambient" results (12/16/2013 and 6/3/2014) and one "routine" result (2/27/2013).

[157] Averages include data with a Hydrologic Event code of "Storm," or a blank Hydrologic Event code and a Method Type of either "Routine, Storm-Impacted" or "Stormwater."

[158] Susquehanna River Basin Commission data appear to be restricted to the Susquehanna River itself. The data are not flagged as "routine" or "stormwater."