Bay out of Balance

Broken System Allows Phosphorus Pollution to Worsen

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Executive Summary

Phosphorus contamination of farmland in the Chesapeake Bay watershed is extensive, an EWG investigation reveals. In one of every five counties in the six-state region, more than half of all soil samples tested are overloaded with more phosphorus than crops can use. Meanwhile, waters draining from these lands carry the excess to local waterways and ultimately the bay.

The findings underscore the failure of past efforts to limit phosphorus pollution

The findings underscore the failure of past efforts to limit phosphorus pollution, a central cause of the growing dead zones in the Chesapeake. This dismal record is hardly surprising, since the six states in the watershed and the federal government have failed to put in place a coherent and common set of recommendations and regulations designed to prevent phosphorus from building up to dangerous levels. The current approach to managing phosphorus appears to be driven by the need to dispose of large volumes of phosphorus-rich manure and sewage sludge in blatant disregard of the need to restore the Chesapeake Bay.

Although the Chesapeake suffers greatly from nitrogen and sediment pollution as well, the phosphorus problem is uniquely the result of largely unregulated human activity – farming. Agriculture, especially poultry farming, is the source of 45 percent of the phosphorus flowing into the bay, much of it from manure generated by livestock and applied to fertilize neighboring fields. Pound for pound, poultry poses a particular challenge because a typical "broiler" chicken excretes three-to-four times as much phosphorus as dairy or beef cattle. Sewage sludge, another agricultural fertilizer in use in the bay watershed, is also a source of excess phosphorus.

Plants require phosphorus to grow, but they can take up only so much. If there is more in the ground than crops need, the soil becomes overloaded and releases the nutrient into local waterways. In addition, vulnerable soils near drainage ditches or stream banks typically suffer rapid erosion and can release large quantities even when soils are not overloaded. Several methods are available to measure soil phosphorus or pollution potential, but none have been used effectively in the Chesapeake watershed to limit phosphorus applications to overloaded soils. As a result, common farming practices result in continuing application of manure, sludge and phosphorus fertilizer. Since phosphorus is a persistent pollutant, it remains for years, leaking out slowly and damaging waterways even with no new applications. The most effective strategy, therefore, is to prevent over-application in the first place.

New data show that phosphorus contamination in the Chesapeake watershed is geographically widespread. EWG's analysis of soil test results indicates that in half the counties in the region, more than 50 percent of all soils tested needed no additional phosphorus for crop production. In one of every five counties, more than half the soil tests held "excessive" levels, a clear threat to pollute local waterways – and ultimately Chesapeake Bay.

The solution lies in setting firm, region-wide limits on manure, sludge and fertilizer use on already overloaded land. States must also begin to collect and make public basic data on existing phosphorus levels in soil. In addition, it is essential to recognize that most current versions of the "phosphorus site index" commonly used to guide application of manure, sludge and fertilizers are deeply flawed and can allow additions far in excess of what crops need. In key agricultural counties in Maryland, phosphorus saturation percentages rose from 1997 to 2002 despite use of the site index. Partly as a result, concentrations in surface waters of the Delmarva Peninsula remain among the highest in the nation, and phosphorus discharges to the bay via the Choptank River increased markedly from 2000 to 2008.

It is time for states to limit additional phosphorus applications to soils already overloaded with higher levels than crops can use. While the U.S. Environmental Protection Agency (EPA) prefers the use of soil saturation percentages to guide application of manure, sludge and fertilizer, the more protective approach would be to use soil test data. Implementing this essential measure would, of course, mean that fewer fields would be available for disposal of manure and sludge. Poultry and other livestock industries as well as municipal wastewater facilities must step forward to develop alternative uses for the millions of tons of excess manure and sewage sludge that we can no longer allow to be applied on land that drains into the bay.

The watershed states must adopt uniform definitions of phosphorus levels ideal for plant growth. Currently, the states do not even agree on a common method to quantify soil phosphorus levels, with the result that the guidance given to farmers changes at state lines. Moreover, state agriculture and environmental protection agencies do little to collect the data needed to inform a meaningful management program. Protecting the bay is a regional problem and would be best served by establishing a rigorous, science-based consensus on measuring and regulating phosphorus levels.

Fixing the problem will require, at a minimum, these three urgent steps:

- The six watershed states must establish a common, rigorous and science-based approach to interpreting soil test phosphorus results and making recommendations to farmers.
- The bay states must assemble all currently available soil test data and collect additional data as needed to complete a comprehensive assessment; data and analyses must be made available to the public.
- The states must set and enforce strict phosphorus thresholds to prevent continued application of the nutrient to already-overloaded soils, ideally based on regionally uniform and protective soil test phosphorus levels. More restrictive measures need to be considered on hydrologically active soils, including those near drainage ditches or streams.

FULL REPORT

Introduction:

Manure, Sludge, Phosphorus and the Bay

The health of Chesapeake Bay is not improving. Three pollutants — phosphorus, nitrogen and sediment — are slowly degrading the health of the largest estuary in the United States.

Phosphorus and nitrogen flowing into the bay feed rampant algae blooms that steal oxygen essential to aquatic organisms, leaving behind dead zones in waters that once teemed with life. Pollution-fed algae and discharged sediments cloud the water, killing the underwater grasses at the foundation of the bay's ecology by blocking the sunlight they need to grow. The bay's ecosystem, including habitat function and fish and shellfish populations, have been reduced to less than half the desired levels, and annual assessments of water quality are consistently very poor (CBP 2010).

Aggressive steps are essential to control all three pollutants and revive the Chesapeake's waters, but phosphorus pollution is unique in that it is primarily derived from a few specific human activities, with low natural inputs. Approximately 11 million pounds of phosphorus contaminated the bay in 2009 alone (CBP 2010). To meet water quality goals, phosphorus loads must decrease by at least 8 percent, despite the expected population increases of 30 percent between 2000 and 2030 (EPA 2009).

Three measures of phosphorus:

Phosphorus is a key plant nutrient and also a powerful pollutant. Three common methods are used by regulators, scientists and farmers to assess how much phosphorus can be safely added to the soil:

Soil test phosphorus – the amount of plant-available phosphorus needed to achieve economically optimum crop yields. Applying manure, sludge or fertilizer based on this conservative measure means soils do not receive more than plants need to thrive.

Phosphorus saturation percentage – the degree to which soils trap phosphorus, preventing it from dissolving into water that drains from agricultural land. The amount released into water typically increases exponentially when saturation reaches between 20 and 30 percent.

Phosphorus site index – Each state in the Chesapeake watershed uses its own index, a calculation that relies on site hydrology as well as soil factors to pinpoint land especially likely to release high levels of phosphorus into local waterways. Current index-based management has failed to produce sufficient pollution reductions. Preventing application of more phosphorus to land with sufficient nutrients is essential to the bay's recovery.

Agribusiness and Bay Pollution

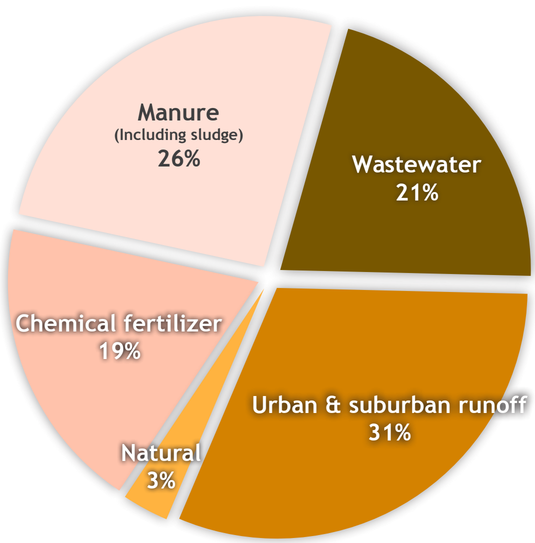
Agriculture is the single most important, and largely unregulated, source of phosphorus entering Chesapeake Bay, contributing 45 percent of the pollution, according to EPA (2009) estimates (Figure 1). The majority of agricultural phosphorus is derived from manure produced by the region's intensive livestock industries. Sewage sludge from wastewater treatment plants is another high-phosphorus waste that is applied to agricultural soils; with little available data (EPA 2010a), its contribution to bay pollution remains largely unknown.

Farmers typically dispose of manure by applying it to neighboring farm fields. After years of application of manure and sludge far in excess of crop needs, soils have become overloaded with phosphorus, resulting in a persistent source of pollution to local waterways and the bay.

Phosphorus is a major component of poultry manure. Pound for pound, the typical meat ("broiler") chicken excretes three-to-four times more phosphorus than a dairy or beef cow (MAWP 2010a). EWG's calculations, based on the 2007 Census of Agriculture data on livestock populations by the U.S. Department of Agriculture (USDA 2009), suggest that poultry is responsible for 50 percent of the manure phosphorus in the Chesapeake Bay watershed. Dairy and beef cattle are responsible for 44 percent, and hogs, sheep and horses produce the remaining 6 percent. Sewage sludge contributions were not assessed because of the lack of data on the extent of land application in five of the six watershed states (EPA 2010a).

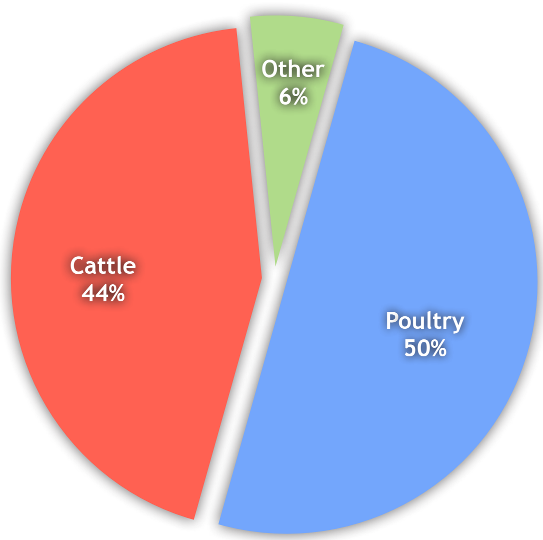
Figure 1: Manure, especially from poultry, is a leading source of phosphorus pollution in Chesapeake Bay

Sources of phosphorus pollution



Source: EPA assessment of Chesapeake Bay pollution (EPA 2009).

Sources of manure



Source: EWG calculations based on USDA's 2007 Census of Agriculture (USDA 2009) and standard livestock and manure coefficients (MAWP 2010a). Sewage sludge contributions not included due to severe data limitations.

From Nutrient to Pollutant

Healthy plants require appropriate levels of available phosphorus in soil as measured by standardized soil tests, and consequently referred to as "soil test phosphorus." However, phosphorus builds up over time if more is applied in manure, sludge or fertilizer than crops need. As soil becomes saturated, it readily releases this persistent pollutant into water, impacting local aquatic ecosystems and the bay. This typically occurs when soils cross a threshold of 20 percent "phosphorus saturation" (Butler 2005).

Some soils, particularly those adjacent to drainage ditches and perennial or intermittent streams, experience high levels of erosion and may contribute large quantities of sediment to water bodies even without high levels of saturation or soil test phosphorus (Sharpley 2001). The "phosphorus site index" has been used to target some of these hydrologically active soils, leading to recommendations or requirements to cut back phosphorus applications on soils calculated to have greater pollution potential. But phosphorus site indices can promote application of phosphorus to already-overloaded soils in fields that are not as vulnerable to erosion or surface runoff or that are farther from streams. Although widely endorsed by all the affected states, current index-based phosphorus management efforts are not achieving the reductions needed to restore the bay.

Many already-overloaded soils in the Chesapeake region will continue to discharge phosphorus into the bay for years even without any additions of phosphorus

Because phosphorus is a persistent nutrient that builds up in the soil, the most effective management strategy is to prevent over-application in the first place. Over-application can occur quickly – one study of farm fields fertilized with chicken litter to supply crop nitrogen found that soil phosphorus levels went from "optimum" to "excessive" within just four years (Staver 2004). While soil and crop properties affect how long it takes to reduce phosphorus levels in over-fertilized soils, another study demonstrated that it took roughly two decades of growing crops without any phosphorus additions to return overloaded soil back to optimum levels (McCollum 1991). Many already-overloaded soils in the Chesapeake region will continue to discharge phosphorus into the bay for years even without any additions of phosphorus-laden manure or sludge.

With so many soils' phosphorus levels already above crop requirements, it is absolutely essential to: (1) reduce phosphorus levels in already-overloaded soils and, (2) prevent buildup to excessive levels in additional soils. Special care is needed for hydrologically active landscapes that experience higher rates of erosion, water runoff to streams, or leaching of phosphorus to groundwater.

Findings:
Phosphorus-loaded Soils are Widespread

New maps and analysis reveal that farm fields with excessive levels of phosphorus in the Chesapeake watershed are commonplace (Figure 2). According to an EWG investigation, in nearly 20 percent of the watershed's counties, more than half the soils tested contained levels of phosphorus considered "excessive." In more than half of the counties, most soils tested had phosphorus levels that were either "excessive" or "optimum," meaning that they likely held more than adequate phosphorus for crop needs. In either case, adding additional nutrient does not improve agricultural productivity and increases the risk of contaminating the bay.

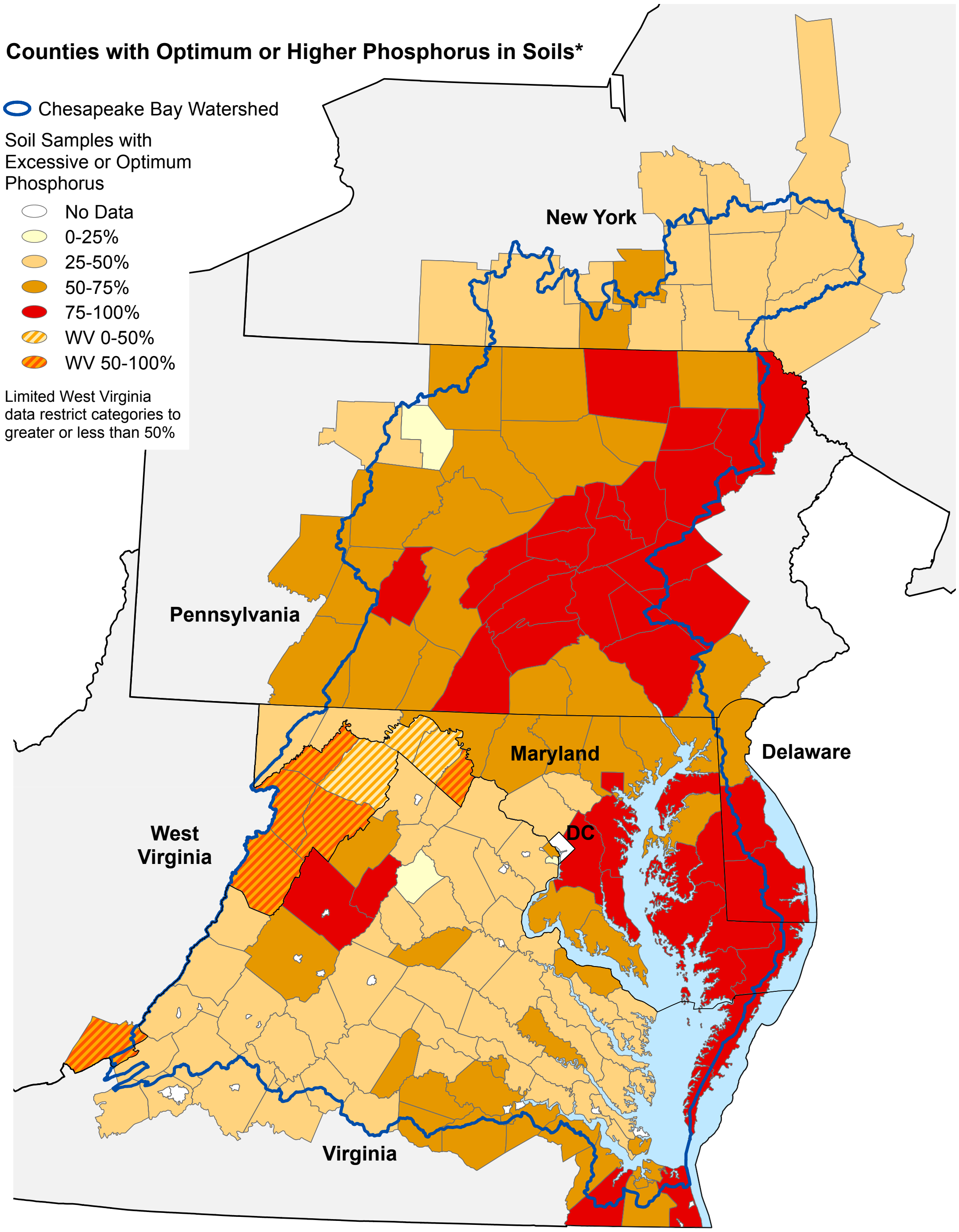
EWG mapped the amount of phosphorus in bay-area soils using data from regional land grant universities where farmers voluntarily send soil samples to be tested for phosphorus and other indicators of fertility.

The amount of phosphorus is typically measured by treating samples with specialized extraction solutions to determine "soil test phosphorus" values. The results are reported in comparison to the amount each university considers "economically optimal" for crop growth. Soils with optimum results supposedly contain all the phosphorus that plants need to thrive, but the range of "optimum" is so broad that many of these soils actually contain enough to eliminate any need for additional applications to replace amounts taken up by growing crops. Soils with even higher amounts are deemed "excessive."

Soil test phosphorus levels are directly correlated with phosphorus saturation percentages (Sims 2002). In particular, soils found to have excessive (sometimes termed "very high") phosphorus in soil tests likely have saturation percentages greater than 20 percent and therefore pose an increased risk of polluting runoff local streams and rivers.

Figure 2: Prevalance of Soils with Excessive or Optimum Phosphorus in Chesapeake Watershed Counties

Counties shaded red or dark orange have a higher ratio of soils with excessive or optimum phosphorus in soil test measurements. Counties shaded in lighter colors have a lower prevalence of such soils. Maps include counties with at least 5 percent of their area in the Chesapeake Bay watershed.



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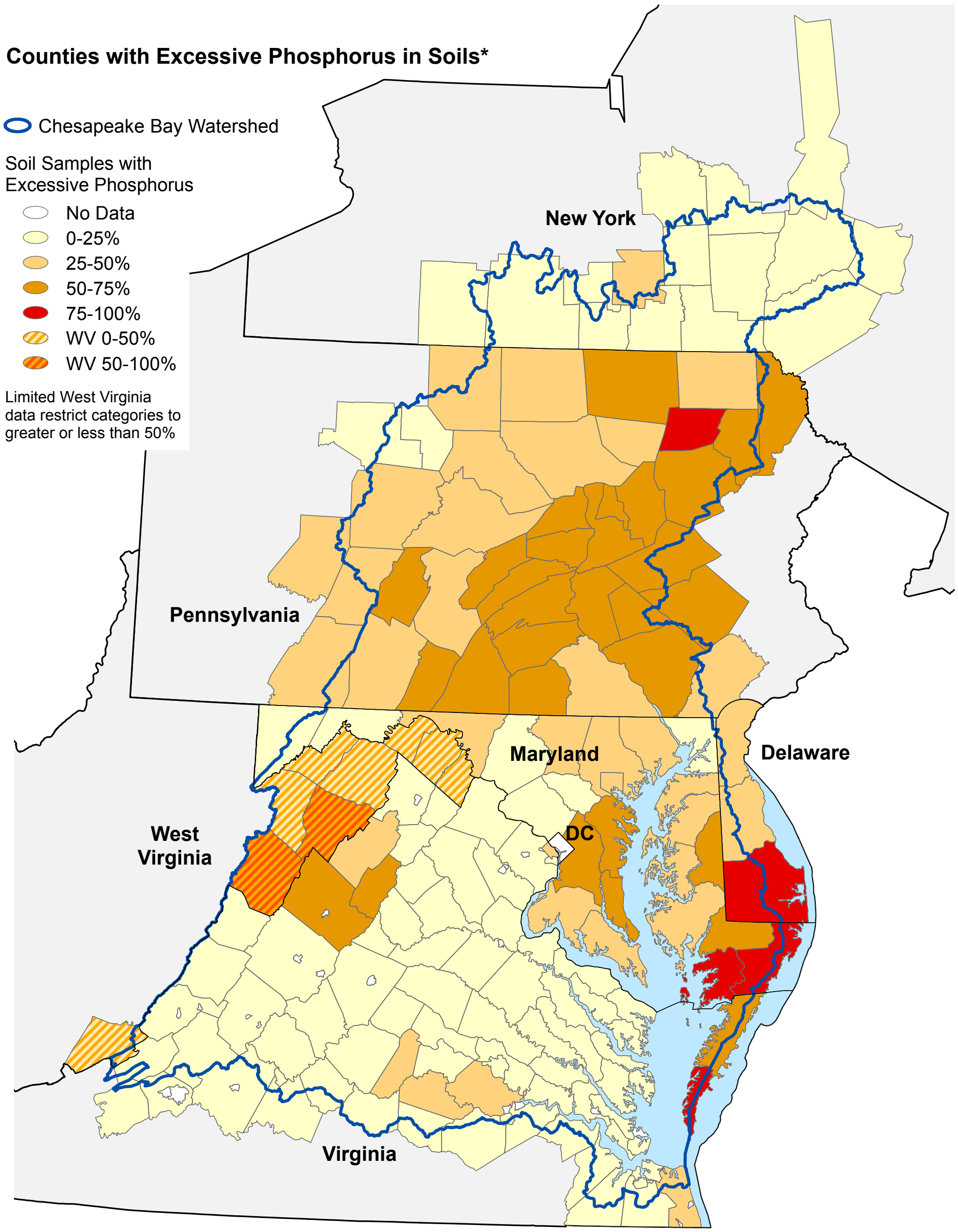

*Sources: Delaware 2009 agricultural samples; Maryland 2000-2003 all samples; New York 2000-2006 agricultural samples; Pennsylvania 2000-2009 all samples; Virginia 2002-2009 agricultural samples; West Virginia 2000-2004 agricultural samples, data limited to averages rather than distributions. See Appendix for details.

Given the limitations of the available data, there is no way to tell whether levels found in samples provided by farmers to university labs accurately reflect the overall condition of agricultural soils in each county. In recent years, soil professionals using standardized protocols have typically collected the samples, reducing one potential source of error and variability in the data (Simpson, personal communication, 2010).

Major Pollution Trends Confirmed

Despite these limitations, EWG's analysis provides troubling confirmation for earlier work that pointed to extensive phosphorus pollution in the watershed. EWG's soil phosphorus maps show significant agreement with a regional watershed map produced by the Chesapeake Bay Program (CBP), an EPA-state partnership. The CBP map identified priority agricultural watersheds that both release significant levels of phosphorus (based on the U.S. Geological Survey's [USGS] SPARROW model for regional interpretation of water quality data) and have extensive cropland that could be targeted for improved management (CBP 2009). Both the EWG and CBP maps pinpoint three key regions of concern: the Delmarva Peninsula, particularly the Eastern Shore of Maryland; the Lower Susquehanna River/Lancaster region of southern Pennsylvania; and the Shenandoah Valley in Virginia and West Virginia.

EWG's analysis provides troubling confirmation for earlier work that pointed to extensive phosphorus pollution

The Mid-Atlantic Water Program (MAWP), a USDA-academic partnership, calculates county-level phosphorus balances every five years. The results also consistently show that a majority of Chesapeake Bay counties are burdened with excess phosphorus (MAWP 2010b). The program's calculations are based on the amount of phosphorus applied in manure and fertilizer minus the amount of phosphorus taken up by harvested crops. These balances, however, do not consider the impact of phosphorus overloading in soils. When land is already burdened with excessive phosphorus, high levels may remain even when harvested crops remove more phosphorus than is added in any one crop cycle.

EWG's analysis of soil test data shows that a majority of soil samples in seven of the ten counties with the highest long-term phosphorus imbalances (1987-2007) do contain excessive levels (Table 1). All ten of these out-of-balance counties are dominated by soils with more than enough phosphorus for crop needs.

Table 1: Out-of-balance counties often dominated by high-phosphorus soils

County	Total phosphorus imbalance 1987-2007 (tons)[1]	Soil samples with optimum or excessive phosphorus (%)[2]	Soil samples with excessive phosphorus (%)[2]
Lancaster County, Penn.	29,403	86	74
Rockingham County, Va.	22,085	85	61
Sussex County, Del.	14,829	97	77
Franklin County, Penn.	10,128	82	62
Augusta County, Va.	7,025	61	23
Wicomico County, Md.	6,547	84	73
Frederick County, Md.	6,443	50	25
Adams County, Penn.	5,881	71	53
Page County, Va.	5,175	83	52
Carroll County, Md.	5,041	68	37

[1]Sum of Mid-Atlantic Water Program estimates of phosphorus balances for 1987-2007.
[2]Percentages of soil samples from each county tested by land grant universities.

New Analysis Reveals New Concerns

The EWG analysis and maps go a step further, pinpointing other counties with a high proportion of soil samples indicating high levels of phosphorus that are not highlighted in the CBP or MAWP data. Soil samples submitted from mid-Maryland counties including Anne Arundel, Calvert and Prince George's, upper Pennsylvania counties including Bradford and Wyoming, and West Virginia counties including Hardy and Pendleton all point to a current problem of high phosphorus levels (Figure 2).

In fact, in two of the ten counties identified by MAWP as having a negative phosphorus balance, more than half the soil samples tested had excessive levels (Calvert County, Md. and Columbia County, Penn.). In three other counties, more than half the soil tests found more than enough phosphorus for plant needs (Charles County, Md., Talbot County, Md., and Westmoreland County, Va.) (Table 2).

Table 2: Counties that appear balanced may have dangerously high levels of soil phosphorus

County	Total phosphorus balance 1987-2007 (tons)[1]	Soil samples with optimum or excessive phosphorus (%)[2]	Soil samples with excessive phosphorus (%)[2]
Charles City County, Va.	-201	31	7
Columbia County, Penn.	-188	82	61
Talbot County, Md.	-181	79	41
Calvert County, Md.	-173	82	57
New Kent County, Va.	-116	45	11
Charles County, Md.	-111	65	35
Morgan County, W.V.	-67	<50	<50
Westmoreland County, Va.	-44	54	10
Elk County, Penn.	-21	33	17
Mathews County, Va.	-5	32	8

[1]Sum of Mid-Atlantic Water Program estimates of phosphorus balances for 1987-2007. A negative value means more phosphorus is exported via crop harvest than is applied via manure or fertilizer additions.
[2]Percentages of county's soil samples tested by land grant universities.

An Overlooked Source of Phosphorus Pollution

More complete nutrient budgets that consider existing levels of soil phosphorus emphasize the importance of this often ignored source of Chesapeake Bay pollution. Combining the university soil test data that EWG analyzed with the nutrient budgets estimated by the Mid-Atlantic Water Program, Kovzelove et al. (2010) calculated surplus manure and phosphorus levels in 11 counties selected for their intensive animal agriculture. The results suggest that the livestock in these counties excrete up to 3,800,000 tons of excess manure, or up to 18,500 tons more phosphorus than local crops need.

Nutrient balances that neglect the phosphorus already present in agricultural soils are flawed because they underestimate the excess phosphorus applied. EWG's analysis, coupled with the more accurate balances calculated by Kovzelove et al. (2010), calls attention to the danger posed by soils that have built up excessive levels of phosphorus over decades of over-application. Immediate action is essential to slow the discharge of this legacy pollutant into the bay.

The System is Broken

All previous attempts to protect and restore Chesapeake Bay have failed. Current methods of managing phosphorus on agricultural land, based on weak guidance derived from phosphorus site index data, have proven entirely inadequate. The solution must be firm, region-wide limits on phosphorus application to already overloaded land. States must also collect and make public basic data on phosphorus levels, which are essential to the success of any and all efforts to reduce pollution of the Chesapeake.

Method Used to Manage Phosphorus Is Flawed

The phosphorus site index is the most commonly used tool to guide agricultural application of phosphorus in the Chesapeake Bay region. The site index was ostensibly designed to identify high-risk fields that are most likely to release significant levels of phosphorus into local waters. An index considers factors including soil test phosphorus, rainfall, erosion and runoff potential, soil type and texture, type of applied phosphorus, method and timing of application and placement of the field in the broader landscape. The score produced by using a site index is linked to the risk of phosphorus loss from a field.

The primary advantage of the site index method is that it considers the hydrology of a particular field and thus can be used to pinpoint landscapes that are more susceptible to phosphorus loss through erosion as well as surface and subsurface flows of water. The index can be useful in identifying unstable or hydrologically active soils that can pollute waterways without having high soil test phosphorus or phosphorus saturation percentages.

Phosphorus Site Index Alone Isn't Working

The site index's greatest flaw, however, is that current versions allow additions of phosphorus that far exceed the needs of plants. In fact, in the Chesapeake region some fields with excessive soil test phosphorus levels continue to receive manure inputs at rates that maintain or increase the level of phosphorus (Sharpley 2001; Maguire 2007; Kovzelove 2010). Even scientists supporting the use of the current site index system note that repeated phosphorus applications beyond crop needs will increase the risk of contamination over time, making this tool unsustainable in the long run (Maguire 2007).

The weaknesses of the site index approach have also emerged in practice. Maryland and Delaware have required use of index-based nutrient management on nearly all commercial farms for the last decade. Yet soil phosphorus data in key agricultural counties of Maryland from 1997 to 2002 suggest that many fields with high levels continued to be treated with manure, resulting in more soils with higher phosphorus saturation (Kovzelove 2010). USGS measurements show phosphorus concentrations in surface waters of the Delmarva Peninsula remain among the highest in the nation (USGS 2004). Levels of phosphorus discharged to the bay from Delaware and Maryland via the Choptank River actually increased over the last three decades, with particularly significant increases between 2000 and 2008 (USGS 2006; Hirsch 2010), despite widespread adoption of index-based nutrient management during this period.

Results of a 2003-2006 regional survey indicate that farmers employ good phosphorus management practices on less than 20 percent of the cropland in the watershed – and just 0.8 percent of the cropland on which they apply manure (USDA 2010). As defined in the recently published draft report from the USDA's Conservation Effects Assessment Project, good management includes practical restrictions on the amount, timing and method of manure or fertilizer application but does not include any consideration of existing levels of phosphorus in soil. Had additional limits on application based on soil test levels been included in the analysis, far fewer fields would have received a passing grade for phosphorus management.

Soil Phosphorus Thresholds Needed

Explicit thresholds – beyond which no additional phosphorus should be applied – must be established and enforced in order to create a more protective system. Moreover, phosphorus management must be designed to gradually reduce the levels in soils that currently exceed the thresholds.

There are two approaches to setting such thresholds. A compromise method uses phosphorus saturation percentages to guide application, while the more protective approach relies on soil test data. Stricter application limits and erosion controls are warranted on hydrologically active lands bordering drainage ditches and perennial or intermittent streams.

Phosphorus Saturation: EPA's Preferred Method

In its recent Chesapeake Bay Protection and Restoration Section 502 Guidance, EPA employs a method of assessing phosphorus needs that fosters intermediate levels of manure application (EPA 2010b). The soil itself can retain some phosphorus not absorbed by plants; phosphorus saturation percentage, mentioned previously, is a means of assessing how tightly bound the phosphorus is. If the saturation is below 20 percent, soil minerals and organic matter will retain much of the nutrient. When saturation climbs above 20 percent, the amount released by the soil increases exponentially (Butler 2005).

EPA recommends no phosphorus application on all federal lands with saturation percentages greater than 20 percent (EPA 2010b). An analysis of more than 400 soil samples showed that phosphorus saturation percentage is correlated with a common measure of soil test phosphorus (Sims 2002), indicating that soils with high soil test levels are typically highly saturated and more likely to release phosphorus into local streams and rivers. Saturation-based guidance is similar to index-based guidance in assuming that soils constitute a giant "sink" for phosphorus-heavy manure, but saturation-based guidance would result in a far greater and more consistent effort to keep this sink from overflowing into the bay.

Soil Test Phosphorus: The Most Protective Method

By assuring that soils do not contain more available phosphorus than crops need to thrive, farmers will once again treat phosphorus primarily as a valuable nutrient in the agricultural landscape. With plant roots eagerly consuming the element, far less phosphorus will dissolve into agricultural waters that drain to the bay.

According to recent phosphorus balance calculations that account for existing soil levels (Kovzelove 2010), fertilization based on state soil test guidance for Maryland, Pennsylvania and Virginia would result in lower levels of applied phosphorus than guidance based on saturation percentage. Considering phosphorus as a nutrient, rather than a waste material requiring the maximum possible level of disposal, is likely to result in a more protective approach.

To date, agricultural pollution controls in the watershed have proven inadequate. It is time for states to further limit phosphorus additions to soils that already have high levels, ideally using soil test evaluations, as well as to erosion-prone regions bordering drainage ditches and perennial or intermittent streams. EPA's 502 Guidance for federal lands, which outlines restrictions for highly saturated soils, may be a useful starting point (EPA 2010b). Any successful, long-lasting effort to reduce phosphorus pollution must eliminate the region's overall phosphorus surplus and draw down soil phosphorus levels in regions that are home to concentrated poultry and other livestock operations (Staver 2001).

Key to the successful implementation of phosphorus limits is the development of alternative uses of excess manure produced by the region's poultry and other livestock. These industries, working with state and federal agencies, must step forward to meet this challenge on behalf of the contract farmers who raise their animals, providing capital as well as scientific and engineering expertise to establish new markets for manure.

Soil phosphorus thresholds would also limit the use of sewage sludge on agricultural lands. While no mechanisms currently exist for poultry and livestock farmers to recoup increased waste-handling costs, operators of wastewater facilities may be able to pass some of the costs of sludge disposal on to their customers (Staver 2001).

States Need to Get on the Same Page

Curiously, each state has its own definition of "optimum" (sometimes termed "high") soil test levels ideal for plant growth, as well as "excessive" (sometimes termed "very high") soil test levels likely to cause environmental degradation. States do not even agree on a common method for quantifying soil phosphorus, and they use varying units of measure (Table 3). These state-by-state differences may reflect political or economic considerations as much as scientific or agricultural ones. As a result, advice to farmers changes at the state line and does not necessarily reflect actual differences in soil.

Pennsylvania provides the most protective advice, suggesting that crops do not respond to additions of phosphorus when soils contain 31-50 parts per million phosphorus (via Mehlich-3 extract, roughly equivalent to 12-to-15 percent phosphorus saturation). Its guidance says that fertilizing soils with higher levels may "adversely affect plant growth and environmental quality" (PSU 2001). In contrast, Delaware considers 101-200 pounds per acre of phosphorus (via Mehlich-3 extract, roughly equivalent to 15-to-24 percent saturation) to be an optimum level, while phosphorus above 200 pounds per acre is considered excessive.

Table 3: States disagree on acceptable levels of phosphorus

State	DE	MD	NY	PA	WV	VA
Optimum soil test level for each state: Higher levels exceed plant needs[1]	101-200 lbs/acre Mehlich-3 P	51-100 FIV Mehlich-1 P	9-39 lbs/acre Morgan P	31-50 parts per million Mehlich-3 P	50-80 lbs/acre Mehlich-1 P	36-110 lbs/acre Mehlich-1 P
Estimated phosphorus saturation[2]	15-24%	12-18%	11-29%	12-15%	13-16%	11-18%

[1] This category is designated "optimum" or "high," depending on the state, and indicates sufficient phosphorus for maximum yield of crop plants, with no or minimal need for additional applications to replace that removed by harvest.

[2] See Study Methods for details on how these estimates were calculated.

Evaluation of excessive phosphorus levels is similarly inconsistent. While New York defines six different levels of excessive soil phosphorus, Maryland provides only a single category. Existing data thus frequently limit a clear assessment of the actual levels of phosphorus in soils testing "excessive."

The variations among the states' definitions of optimum or excessive levels of phosphorus make it impossible to assess the state of the region's soils using a single and consistent metric. The states face a regional problem and would be best served by establishing a rigorous, science-based consensus regarding appropriate and unsafe levels of phosphorus in agricultural soils.

Soil Phosphorus Data Slip Through Agencies' Fingers

Although farming is the leading source of Chesapeake Bay pollution, state agricultural and environmental agencies do not make any systematic effort to collect or analyze soil phosphorus information. Maryland, for example, conducted on-farm implementation reviews of 7 percent of farmers' nutrient management plans in 2009 (MDA 2010), yet made no effort to tabulate or review soil test data readily available as part of these plans.

Virginia poultry and livestock farmers must submit nutrient or manure management plans directly to the state, but the state has yet to take advantage of this ready source of soil data. But crop farmers, even those applying poultry and other livestock manure on their lands, are not required to submit such plans.

In general, the states are ill equipped to deal with the region's severe phosphorus problem and miss easy opportunities to collect baseline data.

Conclusion

The system being used to protect Chesapeake Bay from phosphorus is broken. Soil phosphorus is building to dangerous levels on agricultural land all around the basin. EWG's analysis of these soil test results shows that soils tested in at least half the region's counties contain levels of phosphorus more than sufficient for plant needs. Many of these soils are now a persistent source of pollution to streams, rivers and the bay itself.

Urgent action must be taken to improve the system, including:

- States must establish a common, rigorous and science-based approach to interpreting soil test phosphorus results and making recommendations to farmers.
- States must assemble all currently available soil test data and collect additional data as needed to complete a comprehensive assessment of the state of the basin's soils; data and analyses must be made available to the public.
- States must set and enforce strict thresholds, ideally based on region-wide, protective soil test data, to prevent continued application of phosphorus to already-overloaded soils. More restrictive measures should be considered on hydrologically active soils and those near drainage ditches or streams.

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Appendix A: Study Methods

Land Grant University Laboratories Provide Data

EWG mined records from land grant universities in each of the watershed states, assembling information on phosphorus levels in soil samples voluntarily sent to university labs for analysis. EWG received soil phosphorus data summaries from soil testing laboratories at Cornell University, Pennsylvania State University, University of Delaware, University of Maryland (soil testing laboratory no longer in operation), Virginia Tech and West Virginia University.

Laboratories reported soil test data using a variety of units and nutrient category cut-offs. EWG contracted with Iowa State University's Geographic Information Systems (GIS) Support and Research Facility to construct maps of soil test phosphorus distribution by county, using each state's assessment of "optimum" (or "high") and "excessive" (or "very high") levels. Reflecting the disparate recommendations concerning soil test phosphorus, variations in the data provided by land grant universities in each of the states prevented use of a single set of soil test phosphorus categories for the entire region. Where possible, soil phosphorus tests of non-commercial lands (e.g. garden or turf samples) were excluded. Maps summarize all data collected in the last decade, as indicated in the following table:

State	Data range (years)	Sample types included
Delaware	2009	Agricultural
Maryland	2000-2003	All
New York	2000-2006	Agricultural
Pennsylvania	2000-2009	All
Virginia	2002-2009	Agricultural
West Virginia	2000-2004	Agricultural

Data from West Virginia University were limited to bar graphs indicating average soil test phosphorus values for different crop types found in each county. EWG staff estimated countywide weighted averages using the crop-specific soil test phosphorus averages as well as the total number of soil samples tested for each crop type in each county. When this estimated countywide average fell into the "very high" West Virginia soil test category, more than 50 percent of the soils in this county could be classified as "very high." When the average fell into the "high" category, more than 50 percent of the soils in this county could be considered "high" or "very high" in phosphorus.

Study Limitations

Soil phosphorus levels based on samples submitted voluntarily to university labs may not be fully representative of entire counties, as some farmers may not participate. Nevertheless, land grant universities house the broadest publicly available datasets on soil phosphorus. Some Chesapeake Bay states have access to more complete information on soil phosphorus but do not tabulate or analyze it and consider it confidential. Other states do not make any effort to track levels of this pollutant on agricultural land.

In recent years, submitted samples are typically being collected by soil professionals using standardized protocols, eliminating significant variability concerning the area characterized by each sample (Simpson, personal communication, 2010).

For regions as large as a small state, university data appear to capture representative soil phosphorus information. University of Delaware state data summaries corresponded well with those of three independent laboratories, despite the fact that the summaries were based on samples from different growers (Gartley, personal communication, 2010). Overall, the university data obtained by EWG can be considered useful for assessing broad trends within or across regions (Gartley, personal communication, 2010).

Manure Phosphorus Calculations

Estimates of the populations of livestock in the region were calculated using USDA 2007 Agricultural Census data for each county (USDA 2009), adjusting animal counts by the percentage of the county's area located within the Chesapeake Bay watershed. For a limited number of counties, census data for specific species are withheld to protect the confidential business information of farmers with few local competitors. As a result, aggregate animal population estimates likely represent minimum values.

The manure phosphorus excreted by each species was calculated using manure coefficients provided by the Mid-Atlantic Water Project (MAWP 2010c). The poultry category includes broilers, layers, pullets (using coefficients for hens and pullets not laying) and turkeys (using coefficients for turkeys for slaughter). The cattle category includes beef and dairy cows. The other category includes hogs (using coefficients for "other" [not breeding] hogs and pigs), horses and sheep.

Phosphorus Saturation Estimates

Published correlations between soil test phosphorus measurements and phosphorus saturation levels in regional soils allow estimation of the phosphorus saturation percentages likely encompassed in the optimum ranges of soil test phosphorus determined by each state. Estimations were made using the same assumptions outlined by Kovzelove (2010), based in part on curvilinear relationships provided by Beck (2004), for Maryland, Pennsylvania and Virginia; the Kovzelove (2010) Virginia assumptions for West Virginia; a Beck (2004) curvilinear relationship for Virginia's Eastern Shore and Delaware's Lower Coastal Plain; and linear correlations provided by Ohno (2007) for New York.

Appendix B: County-by-county Soil Test Phosphorus Levels

Counties with Optimum or Higher Soil Phosphorus Levels:

In 75-100% of soil samples tested:

Sussex County	DE	97%
Northampton County	VA	95%
Caroline County	MD	93%
Worcester County	MD	91%
Wyoming County	PA	91%
Dorchester County	MD	88%
Perry County	PA	88%
Accomack County	VA	88%
Northumberland County	PA	87%
Somerset County	MD	86%
Lancaster County	PA	86%
Snyder County	PA	86%
Rockingham County	VA	85%
Lebanon County	PA	85%
Schuylkill County	PA	85%
Lackawanna County	PA	84%
Kent County	MD	84%
Wicomico County	MD	84%
Page County	VA	83%
Montour County	PA	83%
Juniata County	PA	83%
Columbia County	PA	82%
Franklin County	PA	82%
Calvert County	MD	82%
Prince George's County	MD	82%
Berks County	PA	81%
Anne Arundel County	MD	80%
Union County	PA	79%
Kent County	DE	79%

In 75-100% of soil samples tested:

Talbot County	MD	79%
Dauphin County	PA	77%
Bradford County	PA	77%
Luzerne County	PA	76%
Wayne County	PA	76%
Mifflin County	PA	76%
Blair County	PA	76%
Cumberland County	PA	75%

In 50-75% of soil samples tested:

Isle of Wight County	VA	75%
Queen Anne's County	MD	74%
Fulton County	PA	73%
Centre County	PA	73%
St. Mary's County	MD	73%
York County	PA	73%
Clinton County	PA	72%
Adams County	PA	71%
Lycoming County	PA	71%
Bedford County	PA	71%
Amelia County	VA	71%
Dinwiddie County	VA	70%
Greensville County	VA	69%
Carroll County	MD	68%
Tompkins County	NY	68%
Potter County	PA	67%
Surry County	VA	66%
Arlington County	VA	65%
Susquehanna County	PA	65%
Charles County	MD	65%
Huntingdon County	PA	64%
Cumberland County	VA	63%
Chesterfield County	VA	63%
Shenandoah County	VA	62%
Chester County	PA	62%

In 50-75% of soil samples tested:

Nottoway County	VA	61%
Tioga County	PA	61%
Augusta County	VA	61%
Harford County	MD	60%
King William County	VA	60%
Washington County	MD	59%
Cambria County	PA	58%
Somerset County	PA	55%
Baltimore County	MD	55%
Prince George County	VA	55%
Westmoreland County	VA	54%
Cecil County	MD	54%
Indiana County	PA	54%
Sullivan County	PA	53%
New Castle County	DE	53%
Chemung County	NY	52%
Clearfield County	PA	51%
Orange County	VA	50%
Frederick County	MD	50%

In 25-50% of soil samples tested:

Henrico County	VA	49%
Louisa County	VA	48%
Howard County	MD	48%
Chenango County	NY	48%
Delaware County	NY	48%
Essex County	VA	48%
Middlesex County	VA	47%
Onondaga County	NY	46%
Richmond County	VA	46%
Gloucester County	VA	46%
Allegany County	MD	46%
York County	VA	46%
Highland County	VA	46%
Madison County	VA	46%

In 25-50% of soil samples tested:

Goochland County	VA	46%
King and Queen County	VA	46%
Rockbridge County	VA	45%
New Kent County	VA	45%
Montgomery County	MD	45%
James City County	VA	45%
Greene County	VA	45%
Cortland County	NY	44%
Lancaster County	VA	44%
Tioga County	NY	44%
Steuben County	NY	44%
Caroline County	VA	44%
Fauquier County	VA	43%
Buckingham County	VA	43%
Hanover County	VA	42%
Montgomery County	VA	42%
Amherst County	VA	42%
Powhatan County	VA	41%
Botetourt County	VA	41%
Roanoke County	VA	40%
Culpeper County	VA	40%
Broome County	NY	39%
Allegany County	NY	39%
Madison County	NY	38%
Schuyler County	NY	38%
King George County	VA	38%
Otsego County	NY	38%
Prince Edward County	VA	37%
Garrett County	MD	36%
Bedford County	VA	36%
Northumberland County	VA	35%
Alleghany County	VA	34%
Stafford County	VA	34%
Craig County	VA	34%
Warren County	VA	33%

In 25-50% of soil samples tested:

Frederick County	VA	33%
Campbell County	VA	33%
Appomattox County	VA	33%
Elk County	PA	33%
Nelson County	VA	32%
Spotsylvania County	VA	32%
Mathews County	VA	32%
Charles City County	VA	31%
Schoharie County	NY	31%
Herkimer County	NY	30%
Loudoun County	VA	30%
Fairfax County	VA	30%
Clarke County	VA	29%
Prince William County	VA	28%
Fluvanna County	VA	28%
Albemarle County	VA	27%
Bath County	VA	26%

In 0-25% of soil samples tested:

Cameron County	PA	25%
Rappahannock County	VA	24%
Caroline County	MD	93%

In more than half soils tested (West Virginia counties):

Grant County
Hardy County
Jefferson County
Mineral County
Monroe County
Pendleton County

In less than half soils tested (West Virginia counties):

Berkeley County
Hampshire County
Morgan County

Counties with Excessive Soil Phosphorus Levels:

In 75-100% of soil samples tested:

Worcester County	MD	80%
Northampton County	VA	79%
Sussex County	DE	77%
Somerset County	MD	77%
Wyoming County	PA	76%

In 50-75% of soil samples tested:

Lancaster County	PA	74%
Wicomico County	MD	73%
Snyder County	PA	73%
Schuylkill County	PA	72%
Caroline County	MD	72%
Lebanon County	PA	71%
Lackawanna County	PA	71%
Berks County	PA	67%
Perry County	PA	66%
Northumberland County	PA	66%
Mifflin County	PA	64%
Juniata County	PA	64%
Franklin County	PA	62%
Dauphin County	PA	62%
Rockingham County	VA	61%
Wayne County	PA	61%
Columbia County	PA	61%
Union County	PA	59%
Prince George's County	MD	58%
Montour County	PA	58%
Cumberland County	PA	58%
Blair County	PA	58%
Calvert County	MD	57%
Luzerne County	PA	56%
Anne Arundel County	MD	55%
Accomack County	VA	55%

In 50-75% of soil samples tested:

Bradford County	PA	53%
Adams County	PA	53%
Page County	VA	52%
Fulton County	PA	50%

In 25-50% of soil samples tested:

York County	PA	50%
Lycoming County	PA	49%
Bedford County	PA	48%
Dorchester County	MD	48%
Centre County	PA	48%
Potter County	PA	48%
Kent County	MD	46%
Clinton County	PA	45%
Kent County	DE	45%
Susquehanna County	PA	43%
Chester County	PA	42%
Huntingdon County	PA	42%
St. Mary's County	MD	42%
Talbot County	MD	41%
Queen Anne's County	MD	40%
Cumberland County	VA	39%
Carroll County	MD	37%
Tioga County	PA	37%
Sullivan County	PA	37%
Chesterfield County	VA	36%
Charles County	MD	35%
Arlington County	VA	35%
Cambria County	PA	33%
Tompkins County	NY	33%
Harford County	MD	32%
Amelia County	VA	31%
Somerset County	PA	31%
Indiana County	PA	31%
Washington County	MD	30%

In 25-50% of soil samples tested:

Clearfield County	PA	29%
Baltimore County	MD	29%
New Castle County	DE	28%
Shenandoah County	VA	28%

In 0-25% of soil samples tested:

Frederick County	MD	25%
Cecil County	MD	24%
Allegany County	MD	23%
Augusta County	VA	23%
Nottoway County	VA	22%
Henrico County	VA	22%
Highland County	VA	21%
James City County	VA	21%
Howard County	MD	21%
Montgomery County	MD	20%
York County	VA	20%
Roanoke County	VA	19%
Buckingham County	VA	18%
Louisa County	VA	18%
Cameron County	PA	18%
Elk County	PA	17%
Prince Edward County	VA	16%
Greene County	VA	14%
Goochland County	VA	14%
Garrett County	MD	13%
Alleghany County	VA	13%
Orange County	VA	12%
Hanover County	VA	12%
King George County	VA	12%
New Kent County	VA	11%
Dinwiddie County	VA	11%
Rockbridge County	VA	11%
Chemung County	NY	11%
Onondaga County	NY	10%

In 0-25% of soil samples tested:

Isle of Wight County	VA	10%
Delaware County	NY	10%
Fauquier County	VA	10%
Powhatan County	VA	10%
Westmoreland County	VA	10%
King and Queen County	VA	10%
Madison County	VA	9%
Culpeper County	VA	9%
Botetourt County	VA	9%
King William County	VA	9%
Prince George County	VA	9%
Essex County	VA	8%
Chenango County	NY	8%
Appomattox County	VA	8%
Gloucester County	VA	8%
Tioga County	NY	8%
Mathews County	VA	8%
Loudoun County	VA	8%
Broome County	NY	8%
Amherst County	VA	8%
Montgomery County	VA	8%
Greensville County	VA	8%
Frederick County	VA	7%
Charles City County	VA	7%
Steuben County	NY	7%
Lancaster County	VA	7%
Madison County	NY	7%
Cortland County	NY	7%
Warren County	VA	7%
Surry County	VA	7%
Northumberland County	VA	7%
Schoharie County	NY	7%
Fairfax County	VA	7%
Prince William County	VA	7%
Craig County	VA	6%

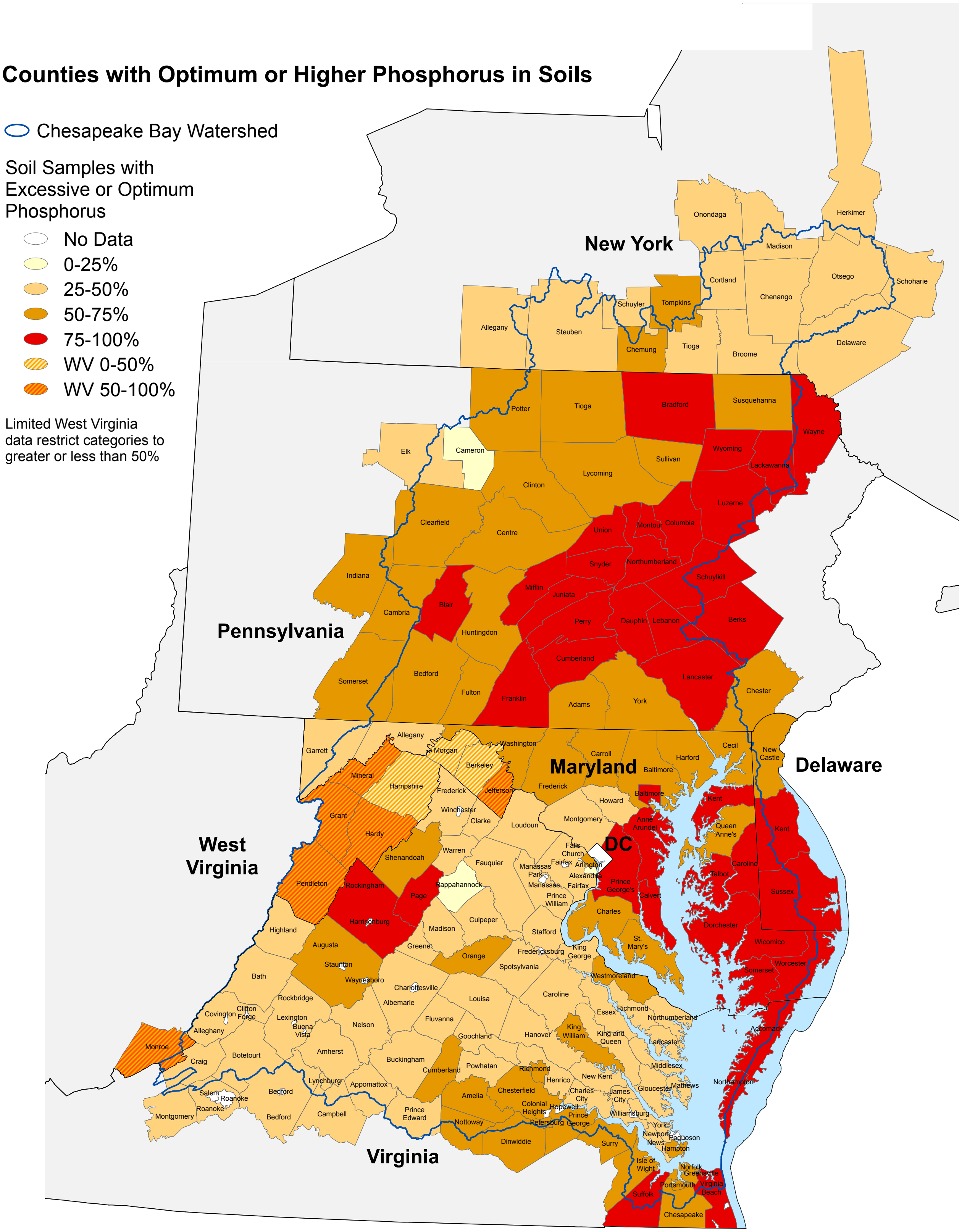
In 0-25% of soil samples tested:

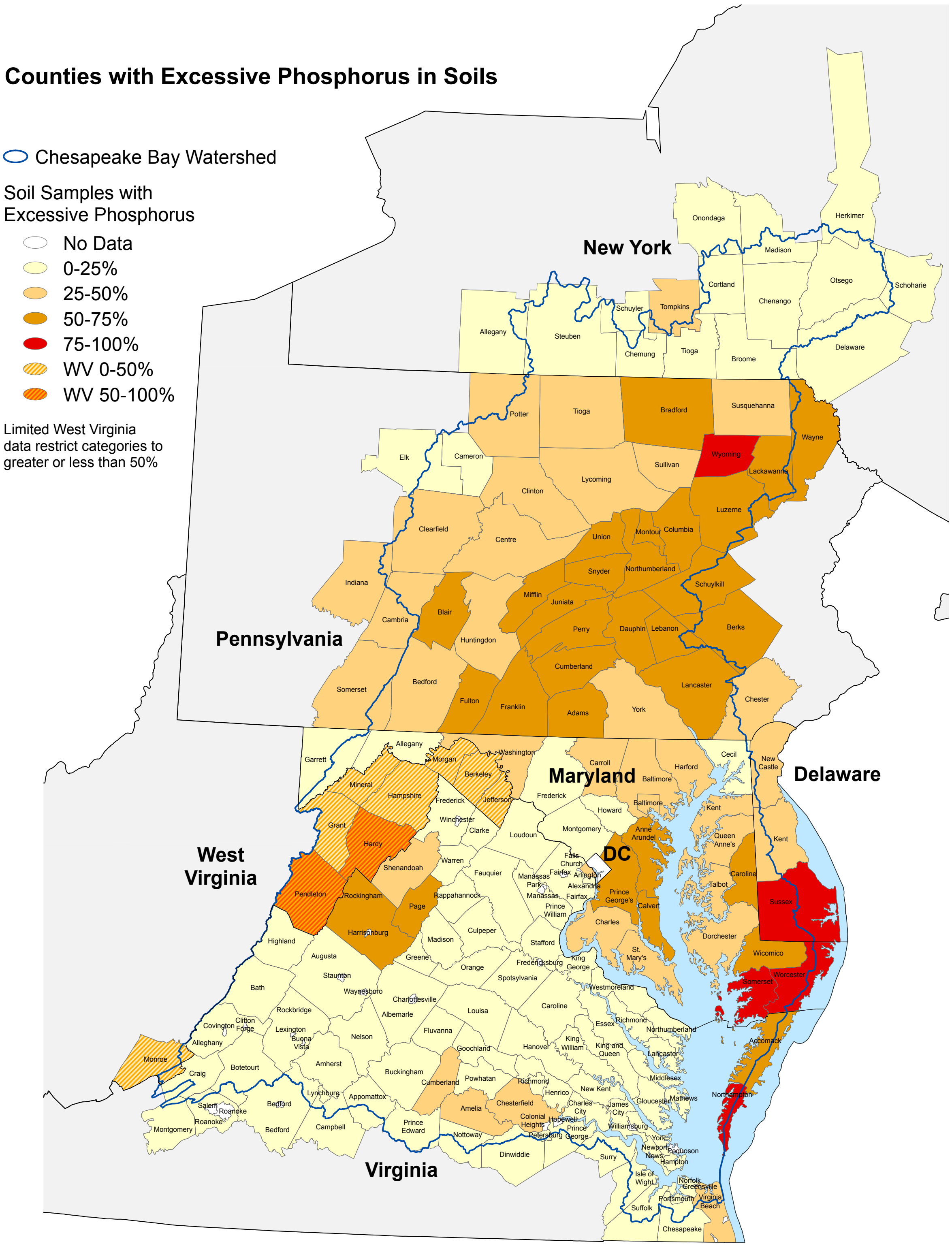
Bath County	VA	6%
Campbell County	VA	6%
Herkimer County	NY	6%
Nelson County	VA	6%
Fluvanna County	VA	6%
Otsego County	NY	6%
Bedford County	VA	6%
Middlesex County	VA	5%
Caroline County	VA	5%
Albemarle County	VA	5%
Spotsylvania County	VA	5%
Stafford County	VA	5%
Allegany County	NY	4%
Clarke County	VA	4%
Richmond County	VA	4%
Schuyler County	NY	4%
Rappahannock County	VA	3%

In more than half soils tested (West Virginia counties):
Hardy County
Pendleton County

In less than half soils tested (West Virginia counties):
Grant County
Jefferson County
Mineral County
Monroe County
Berkeley County
Hampshire County
Morgan County

Appendix C: Zoomable Maps





Counties with Excessive Phosphorus in Soils
Chesapeake Bay Watershed
Soil Samples with Excessive Phosphorus
No Data
0-25%
25-50%
50-75%
75-100%
WV 0-50%
WV 50-100%
Limited West Virginia data restrict categories to greater or less than 50%
New York
Pennsylvania
Maryland
Delaware
DC
West Virginia
Virginia
Onondaga
Herkimer
Madison
Otsego
Schoharie
Cortland
Chenango
Tompkins
Schuyler
Allegany
Steuben
Chemung
Tioga
Broome
Delaware
Potter
Tioga
Bradford
Susquehanna
Wayne
Wyoming
Lackawanna
Sullivan
Elk
Cameron
Clinton
Lycoming
Luzerne
Clearfield
Centre
Union
Montour
Columbia
Snyder
Northumberland
Schuylkill
Indiana
Mifflin
Juniata
Cambria
Blair
Huntingdon
Perry
Dauphin
Lebanon
Berks
Cumberland
Somerset
Bedford
Fulton
Franklin
Adams
York
Lancaster
Chester
Garrett
Allegany
Washington
Carroll
Harford
Cecil
New Castle
Morgan
Berkeley
Mineral
Hampshire
Frederick
Jefferson
Baltimore
Howard
Kent
Grant
Winchester
Clarke
Loudoun
Montgomery
Anne Arundel
Queen Anne's
Hardy
Shenandoah
Warren
Fauquier
Falls Church
Fairfax
Arlington
Alexandria
Manassas Park
Manassas
Prince William
Prince George's
Calvert
Caroline
Talbot
Sussex
Pendleton
Rockingham
Page
Rappahannock
Charles
Harrisonburg
Madison
Culpeper
Stafford
Dorchester
Highland
Augusta
Greene
Fredericksburg
King George
St. Mary's
Wicomico
Staunton
Orange
Spotsylvania
Worcester
Somerset
Bath
Waynesboro
Charlottesville
Westmoreland
Rockbridge
Albemarle
Louisa
Caroline
Richmond
Essex
Northumberland
Covington
Clifton Forge
Lexington
Buena Vista
Nelson
Fluvanna
Goochland
Hanover
King William
King and Queen
Lancaster
Accomack
Alleghany
Monroe
Craig
Botetourt
Amherst
Buckingham
Cumberland
Powhatan
Richmond
Middlesex
Henrico
New Kent
Gloucester
Mathews
Northampton
Salem
Roanoke
Bedford
Lynchburg
Appomattox
Amelia
Chesterfield
Charles City
James City
Montgomery
Roanoke
Bedford
Campbell
Prince Edward
Colonial Heights
Hopewell
Prince George
Williamsburg
Nottoway
Petersburg
Dinwiddie
Surry
York
Newport News
Poquoson
Hampton
Isle of Wight
Norfolk
Greensville
Portsmouth
Virginia Beach
Suffolk
Chesapeake